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J. F. KELLY, Editor

CONTENTS

Vol. V. November, 1928 No. XI

Coming Meetings and Papers..... II

Editorial—
Prosperity and High Wages—By E. G. Grace..... III

Adjustable Speed Main Roll Drives—By M. H. Morgan, Jr..... 467

Developments in Steam Making—By Martin Frisch..... 490

Inspection Trip to Pittsburgh Steel Co..... 497

Junior Membership Division of A.I.&S.E.E.—
Factory Testing of Electrical Apparatus..... 498

Death of Mr. A. G. Place..... 501

Items of Interest—

Direct Current Metal Arc Welding..... 502

Furnace Door Operation..... 503

Arc Welded Structural Building..... 503

Youngstown Sheet & Tube Company Buys Electrical Equipment 504

The Man in the Mill—By Patrick Shea..... 504

(List of Advertisers IV)

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MEETINGS AND PAPERS

BIRMINGHAM DISTRICT SECTION

E. P. WINTERS, *Chairman* BIRGER THELE, *Secretary*

Birmingham, Ala.

Details of the next meeting will be announced later.

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Details of the next meeting will be announced later.

PHILADELPHIA DISTRICT SECTION

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Saturday, December 1 **Engineers Club, Philadelphia, Pa.**

"Electric Heating," by J. R. Eves, Chief Engineer, Falls Electric Furnace Corporation, Buffalo, N. Y.; J. V. Calhoun, Sales Mgr. Harold E. Trent Co., Philadelphia, Pa.

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"A Visit to Russia," by Gordon Fox.

PITTSBURGH DISTRICT SECTION

R. B. DAVENPORT, *Chairman* JOHN F. KELLY, *Secretary*

December (Date Later) Christmas Celebration **Wm. Penn Hotel**

Members and Families.

January 5th **Wm. Penn Hotel**

Symposium—Lubrication.

January **Pittsburgh, Pa.**

"Gas Cleaning and Air Conditioning."
All Day Session.

EDITORIAL

Prosperity and High Wages *

Every year through conferences with employees' representatives Bethlehem makes a report to the employees on matters of joint interest just as it reports to the stockholders at annual meetings. The conferences this year discussed as a matter of vital concern the necessity of maintaining the wage levels upon which American standards of living are based. This issue of the Bethlehem Review, therefore, is devoted to some aspects of this important problem.

AMERICAN industry faces no more important task today than to protect the buying power represented by wages. In the last ten years a new order has been created in our economic life. It is recognized first, that high standards of living are based on the greater earning power of labor and second, that continued prosperity and high wages go hand in hand.

Progressive industrial management seeks, therefore, to enable employees to earn wages as high as can be paid. Even when profits decline or business falls off efforts are made to economize in other ways than by cutting wages. But management alone is powerless to maintain high wages. They can be paid only so long as economic conditions will permit them to be paid.

One of the chief factors affecting this ability to pay them is foreign competition. With European wages far below American wages and consequently costs of production lower abroad, European manufacturers can compete on equal terms with the products of higher paid American labor.

This fact vitally concerns every American worker. Naturally we are all interested in European progress but economic improvement abroad can be accomplished without sacrificing American wages and living conditions. Foreign standards can be raised without reducing ours.

Responsibility in part for protecting his wages rests upon the individual both as an employee and as a citizen.

As a wage earner his responsibility is to help increase production and reduce costs so that his own company can meet competition, sell its products at a profit and thus continue to pay the highest possible wage. Paying men on the basis of individual merit as discussed in this Review is one way to increase wages and reduce costs.

As a citizen the employee's responsibility is to take an active, intelligent interest in company and public affairs. We have reached a point in this country today where thousands of employees are also stockholders with both a payroll and company interest in continued prosperity.

Certain it is, therefore, that as wage earners, stockholders and citizens our outstanding interest is an economic one. If we are mindful of that fact and act accordingly we shall co-operate with each other to promote our company's prosperity and see to it that nothing is done to disturb American living standards which have taken us so many years of hard work to establish.

E. G. Grace
President

*Reprinted from the Bethlehem Review, a bulletin of news for the employees of the Bethlehem Steel Corporation.

INDEX TO ADVERTISERS

A

Alliance Machine Company 539
Allis Chalmers Mfg. Company 561
American Heat Economy Bureau, Inc. 522
Appleton Electric Company 559

B

Bartlett Hayward Company 549
Benjamin Electric Mfg. Co. 517
Blaw Knox Company 514
E. W. Bliss Company 508
Boxill Bruel Carbon Co. 542

C

Chapman Stein Company 510
Chicago Jefferson Fuse & Elec. Co. 556
Clark Controller Co 548
Cleveland Crane & Engineering Co. 526
Condit Electrical Mfg. Corp. 506
Crocker Wheeler Electric Mfg. Co 523
Crouse Hinds Co. 532
Cutler Hammer Mfg. Co. 531–527

D

DeLaval Steam Turbine Co. 535–543
Delta Star Electric Co. 541
M. H. Detrick Company 570
Doubleday Hill Electric Co. 540
Duquesne Light Co. 547

E

Economy Fuse & Mfg. Co. 566
Electric Controller & Mfg. Co. 519
Electrical Engineers Equipment Co. 534
Electric Machinery Mfg. Co. 555
Electric Service Supplies Co. 543
Electro Dynamic Co. 564

F

Farrel Birmingham Co., Inc. 512

G

Gears & Forgings, Inc. 520
General Electric Company Cover 4

H

Harnischfeger Corp. 551
Hyatt Roller Bearing Co. 533

I

Ideal Commutator Dresser Co. 534
International Combustion Eng. Corp. 525–507
Iron City Electric Co. 544
Iron and Steel Exposition 540
ITE Circuit Breaker Co. Cover 3

J

Jewell Electrical Instrument Co. 541
Johns Manville Corp. 529

K

Keystone Lubricating Co. 528

L

Lapp Insulator Company 560

M

Martindale Electric Co. 521
Moloney Electric Co. 536
Morgan Construction Co. 542
Morgan Engineering Co. 530
Morganite Brush Co. 546
Monitor Controller Co. 513

N

National Air Filter Co. 545
National Carbon Company 509
New Departure Mfg. Co. 565
Nichols Lintern Co. 569
Norma Hoffmann Bearings Corp. 553
R. D. Nuttall Co. 558

O

Ohio Electric & Controller Co. 524
Orange Roller Bearing Co. 515

R

Railway & Industrial Engineering Co. 516
Reed Air Filter Co. Front Cover
Reliance Electric & Engineering Co. 552
Roller Smith Company 538
Rowan Controller Co. 546
Rumsey Electric Co. 539

S

Stackpole Carbon Co. 550
Standard Underground Cable Co. 537
Shepard Elec. Crane & Hoist Co. 563
Smith & Serrell 538
SKF Industries, Inc. 567
Square D Company 568

T

Thompson Electric Co. 535
Tool Steel Gear & Pinion Co. 537
Timken Roller Bearing Co 518
Trico Fuse Mfg. Co. 554

U

United States Graphite Co. 536
R. E. Uptegraff Mfg. Co. 545

V

V. V. Fittings Company 562

W

Westinghouse Elec. & Mfg. Co. Cover 2–511
Weston Electrical Instrument Corp. 544
Edwin L. Wiegand Co. 557

Adjustable Speed Main Roll Drives

By M. H. MORGAN, JR.*

The first section of this article appears in the October issue. It is a digest of the essential information bearing upon the application and use of adjustable speed A.C. and D.C. main roll drives.

For the executive or non-technical man there is provided in tabular form so that it is instantly available and understandable the essential facts of performance, usual application and comparative cost for each of the practical types of alternating and direct current adjustable speed mill drives. For the engineer or operator there is in addition the necessary detailed description and explanation to make clear the operation of each and its most advantageous use.

The general purpose and scope of the article is explained further in the "Introduction" in the October issue. The first installment covered direct current drives and the various methods of obtaining more than one speed from the standard induction motor without the use of auxiliary machines and stated the general principles of the Kramer, Scherbius and Frequency Converter Sets. What follows is the detailed description of these sets and the Brush Shifting A.C. motor and the comparison of Alternating and Direct Current drives.

KRAMER SET—CONSTANT H.P. TYPE

FOR commercial reasons this is much the more commonly used type of Kramer set. It consists simply of a standard wound rotor induction motor, a shunt or compound wound DC motor mounted on the same shaft or coupled to it, and a standard rotary converter through which the slip rings of the induction motor are connected to the DC machine.

Fig. 9 shows a schematic diagram of connections of such a set. Standard synchronous converters are built for 6 phase operation because this gives a better distribution of heating in the coils of the machine and consequently a greater rating may be obtained from a given machine so connected than if it were 3 phase. For this reason both ends of each phase of the main motor secondary winding are brought out to slip rings and a standard 6 phase converter used. Separate DC excitation is supplied for both the DC motor and the converter and switches included for connecting the main motor to resistance for starting and for transferring it to the converter afterward to obtain reduced speed.

Operation

The converter is continuously supplied with full field excitation so that it runs at a synchronous speed corresponding to the main motor slip frequency and therefore converts this slip frequency to DC at its commutator from which point it is absorbed by the DC machine and returned to the drive as mechanical load torque.

To start the drive the main motor is brought up to speed by the use of secondary resistance and then with the drive running light and no excitation on

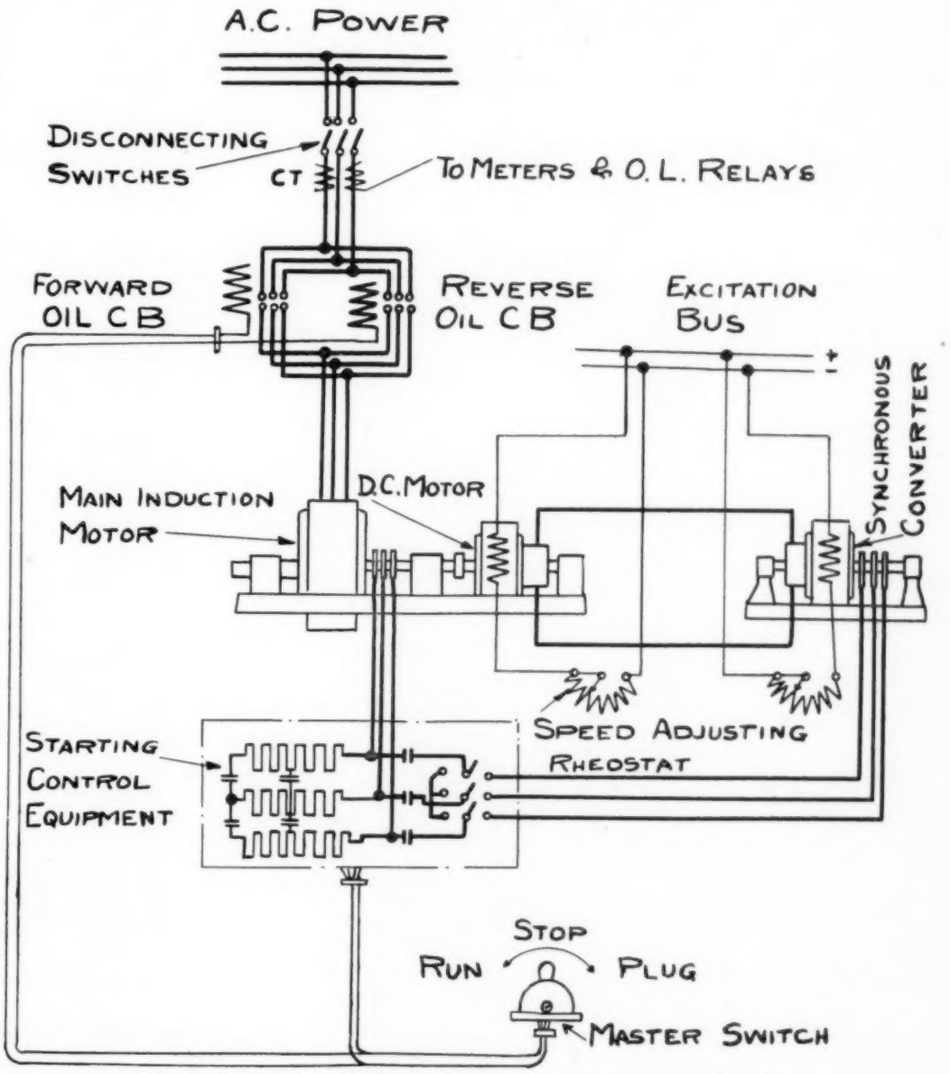


FIG. 9—Schematic Diagram Kramer Set Constant HP. Type.

*Engineering Dept., Edgar Thomson Works, Carnegie Steel Company, Braddock, Pa.

the DC motor but full field on the converter the slip rings of the main motor are connected to those of the converter through the transfer switches. The converter will then start up and idle along at a speed corresponding to the slip frequency of the main motor secondary, and since this slip will then be only about 1%, its speed will be quite low.

To set the speed at a desired lower value excitation is gradually supplied to the field of the DC machine in a pre-determined direction so that its emf acting through the converter "bucks" that of the main motor secondary and the drive continues to slow down as long as this excitation is being increased, the converter meanwhile increasing in speed as the slip frequency of the main motor increases. The speed is stable for a given setting of the DC machine field rheostat, and if the DC motor be shunt wound the change of speed with load is only slightly larger, due to the added resistance of the rotary and DC machine windings, than that of the main motor operating alone.

When it is desirable to give the drive a decidedly drooping speed characteristic as is necessary if a flywheel is used, the DC motor is compound wound. Then the effect of the series turns on the field of the DC machine and the speed of the drive, when the load rises, is the same as if the shunt field current had been increased with the rheostat so that the speed falls off considerably with load.

Current Voltage Frequency Conditions in Secondary Circuit

Fig. 10 shows the conditions of operation of the auxiliaries for a Kramer set of this type over the various parts of its speed range. The particular set chosen for the illustration has a rating of 1000 HP and a synchronous speed of 600 RPM and permits a 25% speed reduction to 450 RPM. According to the statements already made its auxiliary machines must handle a maximum of 25% of the 1000 HP rating or 250 HP. These curves are also extended to show the same quantities when the speed of the drive is increased 25% above synchronysm to 750 RPM. These figures are theoretical only and meters in the various circuits would read a few per cent different from them because of losses in various machines.

Curves A, B, and D show the HP, torque and voltage respectively of the DC machine. It will be noted that these vary directly with the speed reduction and that the HP delivered at the minimum speed 450 RPM is the limiting condition for the DC machine and will determine its physical size and approximately its cost.

Curve C shows the frequency on the converter slip rings, which being the slip frequency of the main motor varies directly with the speed reduction and of course the speed of the converter varies directly with this frequency. The AC to DC voltage ratio of the converter is constant, being fixed by its design, and the AC voltage delivered to it is fixed for a given speed reduction by the design of the main motor secondary and varies directly with the speed reduction. Thus the DC voltage is fixed in value by the design of these two machines and varies directly with the speed reduction.

Summing up then, we may say that (1), for a given load output, the frequency, voltage, and power applied to the converter, its speed, and the voltage and power applied to the D.C. machine (since the converter handles its entire output) all increase directly with the per cent variation from synchronous speed in either direction, but that (2), the current in the entire secondary circuit composed of the main motor secondary, the converter, and the D.C. machine changes only with the load torque regardless of the speed at which it is delivered.

Converter Rating Required

The synchronous converter used in this case was a standard 500 KW, 25 cycle, 6 phase, 600 volt DC machine, having a current capacity of about 840 amperes D.C. The 250 HP which it is required to handle here at a voltage of about 250 DC amounts to about 188 KW and 740 amperes and it is then operating on 15 cycles and therefore running at 60% rated speed. The current capacity of the machine is thus ample for this duty and the DC voltage per cycle (250/15=16-2/3) is both below that of the machine rating (600/25=24) and yet not too far below it for the converter to have a good pull-in torque.

As both the duty required of the converter and its capacity vary directly with the frequency applied to it within the limits of its rating a converter which is adequate for a set having a maximum reduction of 25% below synchronism will also be adequate for the same set over a somewhat greater range and vice versa, the same converter will be required even though the set has a much smaller speed range.

It should be noted that the 60 cycle power supply favors a more economical use of the converter than a 25 cycle supply would. The slip frequency for a given speed reduction largely determines the per cent of normal rating at which the converter may be used, and the closer to normal the machine operates at maximum load, the closer to normal may be its rating. Since the standard converter is a 25 cycle machine the higher frequency power supply results in a slip frequency closer to this value than a 25 cycle system. Thus while the frequency at the maximum speed reduction in this case was 25% of the line frequency or 15 cycles, it would have been only 6¼ cycles had the power supply been 25 cycles. This would have required a much larger and more expensive converter than was actually used.

Operation Near Synchronism

Kramer sets of either type will not carry full rated load while the speed is within a few per cent of synchronism, either above or below. This is due to the fact that the frequency of the AC power applied to the rotary is then very low and is in fact theoretically zero at synchronism and consequently the machine falls out of step quite easily. Thus if the drive be operated on a 60 cycle power source and be set for a speed 3% below synchronous at light load the frequency on the rotary would be 1.8 cycles. If now full load be suddenly applied, the motor slip will be increased to about 6% and the frequency on the rotary to 3.6 cycles. To remain in step now the converter must instantaneously double its speed, and being unable to do this it drops out and shuts down the drive.

Operation Above Synchronism

Due to this condition it has not been the practice of the manufacturers to sell Kramer sets for

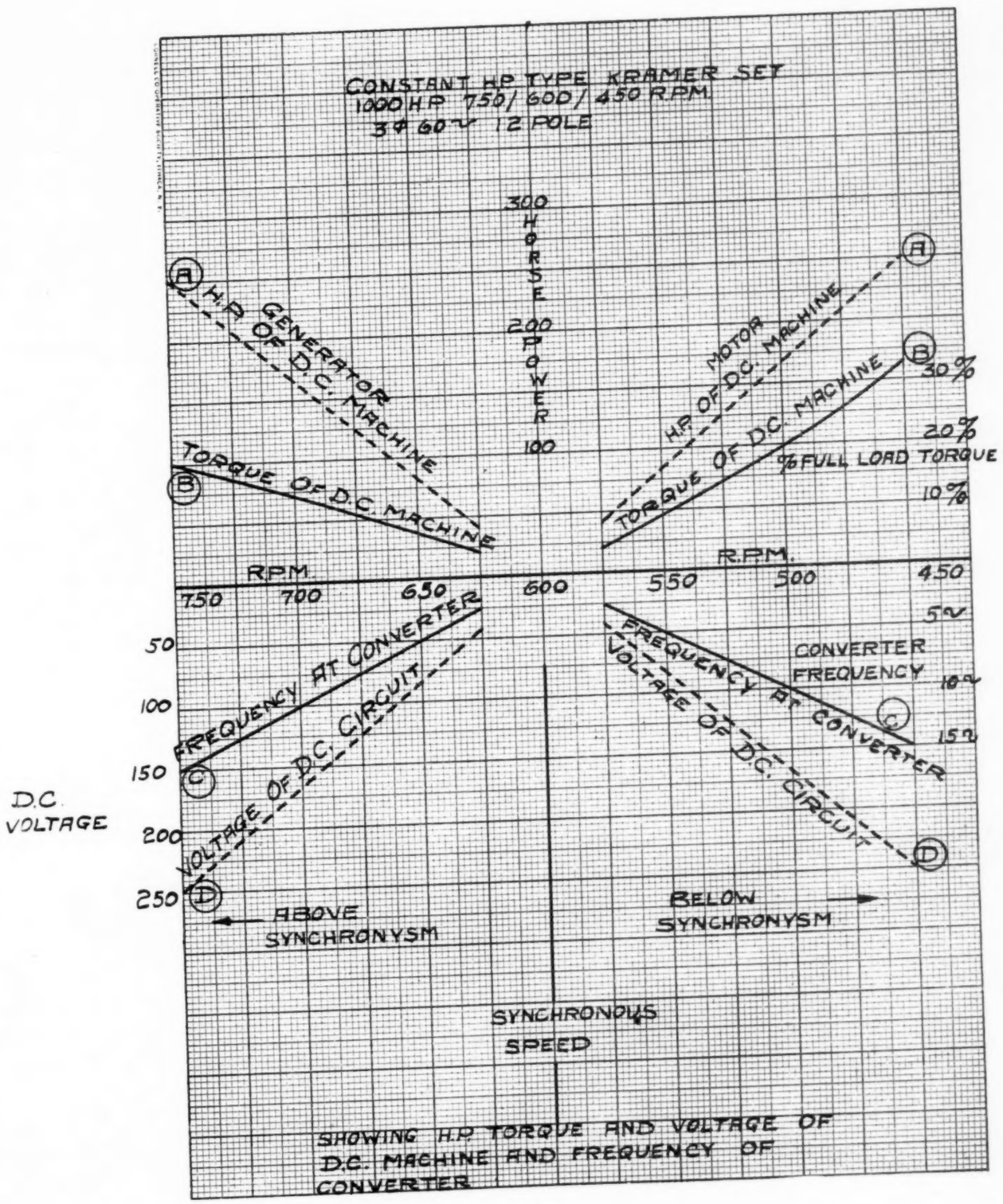

CONSTANT HP TYPE KRAMER SET
1000 H.P. 750/600/450 R.P.M.
3 ϕ 60 ~ 12 POLE
300
HORSE
200
POWER
100
H.P. OF D.C. GENERATOR
TORQUE OF D.C. MACHINE
H.P. OF D.C. MACHINE
TORQUE OF D.C. MACHINE
30%
20%
10%
% FULL LOAD TORQUE
R.P.M.
750 700 650 600 550 500 450
5~
10~
15~
50
100
150
200
250
FREQUENCY AT CONVERTER
VOLTAGE OF D.C. CIRCUIT
FREQUENCY AT CONVERTER
CONVERTER FREQUENCY
VOLTAGE OF D.C. CIRCUIT
D.C. VOLTAGE
ABOVE SYNCHRONYSM
BELOW SYNCHRONYSM
SYNCHRONOUS SPEED
SHOWING H.P. TORQUE AND VOLTAGE OF D.C. MACHINE AND FREQUENCY OF CONVERTER

FIG. 10.

operation above synchronysm but when after their installation it has become necessary or desirable to do so they have co-operated with the purchaser in making the necessary small changes in control to do this. Several such sets are now being worked above synchronous speed to allow economical production of sections not contemplated when the drive was installed.

When the drive is to be operated above synchronism the main motor is started as before and its secondary transferred to the converter. Then with friction load only on the drive excitation is slowly applied to the DC machines but in a direction opposite to that required to reduce the speed. The converter has been running slowly in the direction which it ran before and it now slows down and reverses while the drive accelerates above synchronism as more and more excitation is applied to the DC machine. The speed will be constant and the machines stable for a given full field setting on the DC machine as before. The current in the DC circuit formed by the converter and the DC machine does not reverse although the voltage of this circuit does, and the DC machine which formerly operated as a motor now becomes a generator.

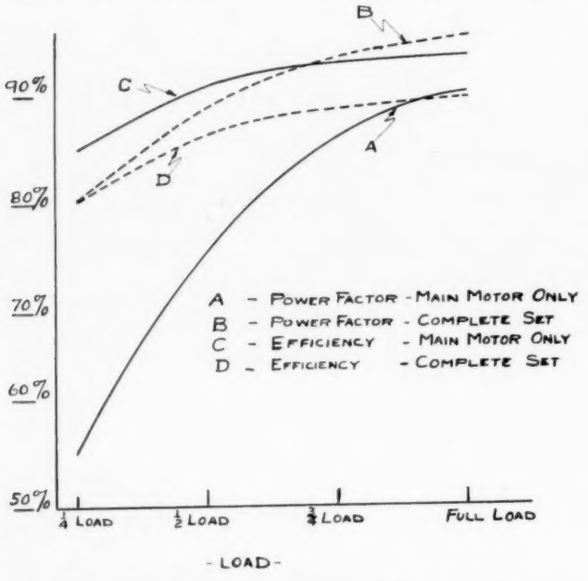


FIG. 11—Power Factor and Efficiency of Constant HP. Type Kramer Set and of Main Motor Only. Rating—1000 HP. 600/450 RPM.

When taken through synchronism in this manner the set will usually carry about 10% normal load which will in most cases be sufficient to carry the mill and motor friction but does prevent taking a drive having a flywheel above synchronism.

Fig. 11 shows typical efficiency and power factor curves for a Kramer set and the same quantities for the main motor alone. The losses of the auxiliaries necessarily makes the overall efficiency of the set less by several per cent than that of the main motor alone. The field of the rotary converter is constantly excited to a value which gives that machine a slightly leading power factor, and the effect is to better the power factor of the set, but since the amount of this correction effect is limited the final result is dependent upon the inherent power factor of the main motor.

Speed Range

As indicated in the foregoing the limit on the allowable variation from synchronous speed is the capacity of the auxiliaries, which must be larger and therefore more expensive for a greater speed range. Thus if the set is to allow 50% speed variation the DC machine must be capable of delivering ½ of the main motor full load rating at ½ its speed, which is equivalent to the full HP rating at full speed and means that this DC machine will be quite as large and probably more expensive than the main motor.

Most Kramer sets provide a maximum speed reduction of 25 to 35%, but some are used with which this is extended to a maximum of 50%.

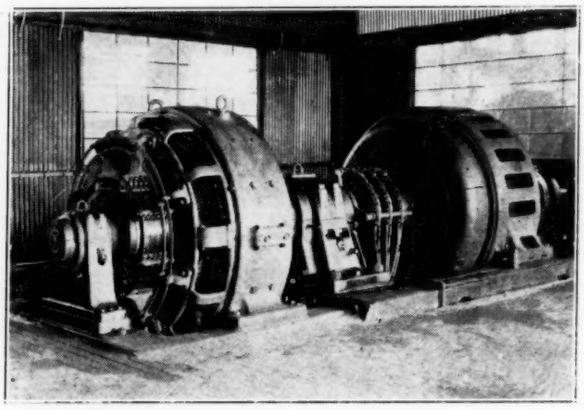


FIG. G—3000 HP Kramer Set Providing 40% speed reduction. Note that DC. Auxiliary machine is as large as main induction motor.

KRAMER SETS—CONSTANT TORQUE TYPE

The principal difference between this and the constant HP type of drive already described is in the use of the DC machine. Fig. 12 shows the main connections of the constant torque type and indicates that while the electrical connection of the DC machine to the main motor secondary through a synchronous converter is unchanged there is no longer any mechanical connection between them.

The DC machine is direct connected to an AC synchronous or induction machine whose primary windings are connected to the power lines so that the difference between the electrical input to the main motor from the power line and the mechanical load torque which it delivers may be returned to the line for speeds below synchronism or supplied from it for speeds above synchronism.

The capacity required of auxiliaries at a given speed is approximately—Load HP x $\frac{\text{Slip}}{1 \pm \text{Slip}}$ using the plus sign for speeds above synchronism and the minus sign for speeds below. Thus for a set rated 1250/1000/750 HP, 750/600/450 RPM the auxiliaries would handle at 750 RPM $1250 \times \frac{0.25}{(1 + 0.25)} = 250$ HP and at 450 RPM $750 \times \frac{0.25}{(1 - 0.25)} = 250$ HP.

These are the maxima and determine the capacity required, but of course the duty will be less at intermediate speeds for the same loads. The frequency and voltage on the converter as well as the voltage on the D. C. machine vary directly with the percentage variation from synchronous speed while the current in the entire secondary circuit varies only with the load and is independent of the main motor and its speed as well as that of the induction or synchronous machine connected to it may be chosen to give the most economical design.

The starting and operation of the set is practically the same as that of the constant HP type. It has the same inability to carry more than about 10% load at speeds within a few per cent of synchronism, and the same ability to operate above synchronous speed once it is taken through this zone. It includes the same power factor corrective effect and is likewise made up of standard apparatus. This type of

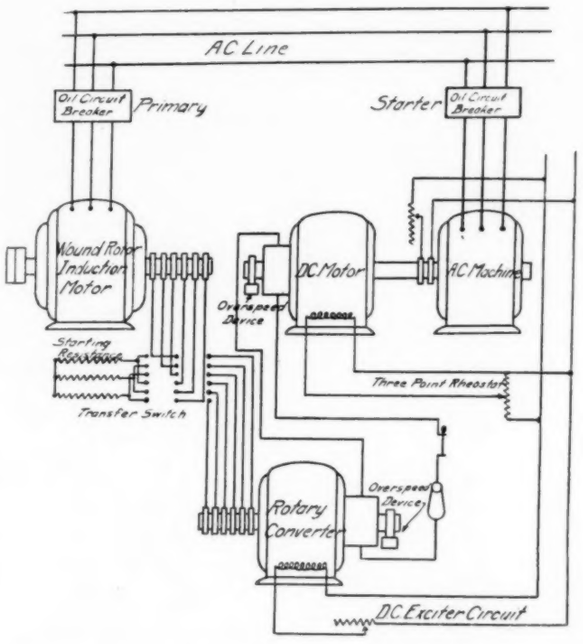


FIG. 12—Schematic Diagram of Constant Torque Type Kramer Set.

Kramer set has an inherent cost disadvantage arising from the fact that it includes one more machine than the constant HP type which prevents it being used to any considerable extent. The additional machine is the AC synchronous or induction generator direct connected to the DC motor and it adds materially to the cost of the drive and also reduces its efficiency to some extent since the power handled by the auxiliaries now passes through 3 such machines instead of 2. Accordingly where constant torque only is required a Kramer set of the constant HP type is often used and given a constant torque rating. This results in no hardship to the purchaser other than a small loss in efficiency when operating near minimum speed and the additional capacity available there sometimes proves useful.

Provision for Future Conversion of Induction Motor Drive to Kramer Set

Sometimes it is known at the time a single speed induction motor drive is installed that future changes to the mill or its product will necessitate the conversion of the drive into an adjustable speed set. Then it becomes important to know what provision should be made in the original drive to facilitate the change.

Necessary provisions for the addition of Kramer equipment are a shaft extension for coupling the DC machine to the main motor and space for its location. This is necessary if the drive is to be constant HP rated and desirable even if it is to be rated con-

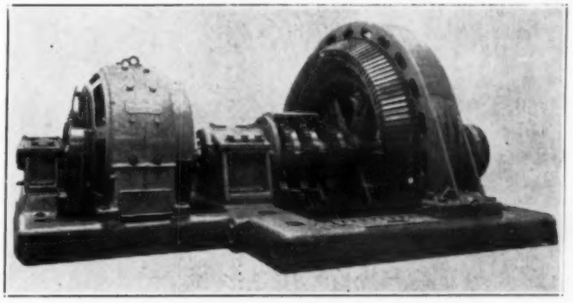


FIG. H—Typical Constant HP. Type Kramer set rated 1000/750 HP. and providing 25% speed reduction. Note that DC. Auxiliary Machine is much smaller than main induction motor.

stant torque, for often a constant HP type Kramer set will be offered and be more economical for a constant torque application. Desirable though not absolutely necessary provisions are the bringing out of both ends of all three phases of the secondary winding to six slip rings and the choice of the secondary current and voltage such that the open circuit voltage across one phase (between slip rings

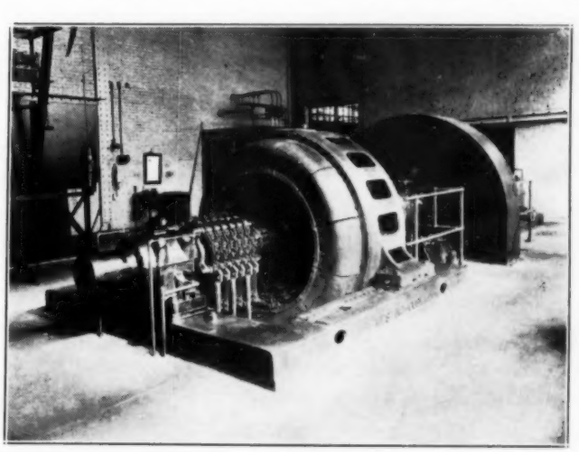


FIG. I—High Speed Mill Type Induction Motor. Note that each end of each phase of secondary is brought out to slip rings and shaft is extended for future conversion to adjustable speed set.

Nos. 1 and 4) when the motor is stalled (known as the "locked" secondary voltage) is close to either 1050 or 440 for a 60 cycle drive and close to 420 or 176 for a 25 cycle drive.

Both of these latter provisions tend to give the maximum economy in synchronous converter size. The first does so because a given converter has a greater load capacity for 6 phase operation than for 3 phase operation and the standard converter is therefore built for 6 phase service. The second makes the full speed, full load DC voltage of the converter about the same as that of the standard 250 or 600 volt 25 cycle machines and permits using a machine rated at say 500 KW in a set when the required capacity of the converter for that set is 500 KW. A departure from this value will reduce the permissible rating to some extent. The operating characteristics of the converter also are somewhat better when this condition is fulfilled than otherwise.

SUMMARY OF CHARACTERISTICS—KRAMER SETS

This summary of characteristics of Kramer sets is intended to include all features of construction and performance which are pertinent to their operation and most advantageous use, and necessarily includes both advantages and disadvantages as well as those qualities which may be of value in one application and a detriment in another.

Best Adapted to 60 Cycle High Speed Service

On 60 cycle systems the converter will be smaller and less expensive for a given size drive than on 25 cycle systems. Similarly the D.C. machine of a constant HP set will be increased in size and cost if the speed of the drive is lowered because this machine must run at the same speed as the main motor.

Best Adapted to Constant HP Drives

The constant HP type of Kramer set includes three rotating machines while the constant torque type requires 4, so that its cost is thereby increased and efficiency slightly decreased. The constant HP type is usually supplied for constant torque drives on this account, and while its operation is satisfactory it will have a cost disadvantage.

Best Adapted to Small Speed Range

The set is guaranteed for single range operation only and as a rule the practical limit is a reduction of 25 to 35% from synchronous speed although this may reach 50%.

Cannot Carry Full Load Close to Synchronism

Due to the resulting low speed of the converter the set will not carry its full load within a few per cent of synchronism, either above or below. However the main motor may be cut loose from the auxiliaries and operated non-regulating at its standard speed slightly below synchronous.

Made Up of Standard Machines

This is the outstanding feature of the Kramer set. The main induction motor, the rotary converter and the direct current machine are each the same machines as would be supplied for a single speed mill drive, mill converting service, or a D.C. mill drive, respectively, with two exceptions. One is the bringing out of both ends of each phase of the main motor secondary winding to six slip rings for greater economy in converter size and the other is the occasional use of non-magnetic spacers in the commutating poles of the converter when it is known that high peak loads will be encountered. This makes the inspection and repair of the drive easier for the average operator who is relatively familiar with the machines separately used.

FREQUENCY CONVERTER SETS

The frequency converter type of A.C. adjustable speed drive is sold, guaranteed, and operated for speed ranges extending both above and below that of the main motor alone. It will carry full load and be stable in operation over any part of the range, including speeds close to synchronism and while relatively less of these sets have been sold than of the older and better known types yet its use is increasing. It is limited almost entirely to 25 cycle systems although some sets are in use on 60 cycle systems.

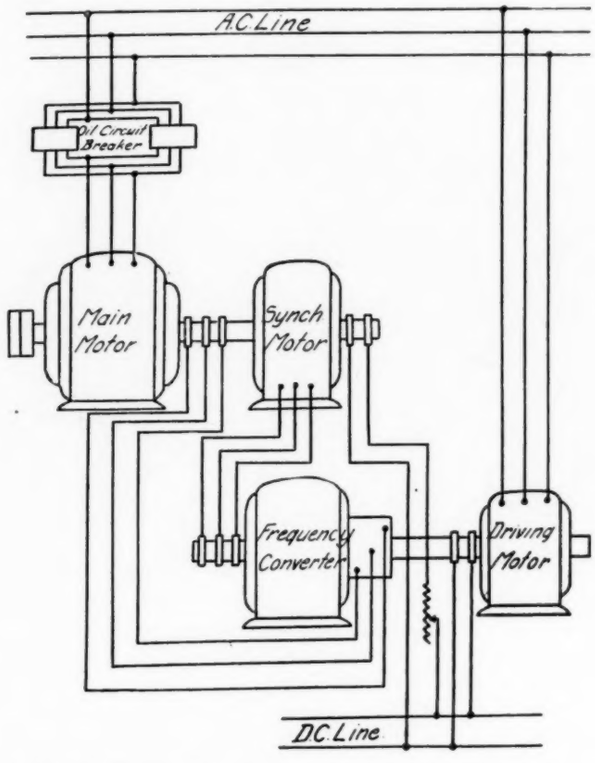


FIG. 13—Schematic Diagram Constant HP. Type Frequency Converter Set.

CONSTANT HORSEPOWER TYPE

The drive consists essentially of machines performing the same functions as those of a Kramer constant HP drive. Thus it has for a main motor a standard wound rotor induction machine and mechanically connected to it a second machine which serves as a motor for speeds below synchronism and as a generator for speeds above, while a third machine serves to convert the energy of the main motor secondary. There is in addition a small driving motor which supplies the losses of the converting machine.

Fig. 13 shows the main connections of the machines composing this drive. The main motor is a standard wound rotor machine except for the shaft

extension for coupling to the auxiliary machine. The auxiliary machine is a standard synchronous motor wound for the same number of poles as the main motor. The frequency converter is a special machine whose function it is to convert the frequency of the synchronous machine to that of the main motor secondary for all speeds without affecting voltage. Then with the connections shown, a change in the setting of the field rheostat of the synchronous machine will change its terminal voltage which, being impressed upon the main motor secondary, will buck or boost its generated voltage and vary its speed above or below synchronysm, depending upon the polarity of the excitation of the synchronous machine. As the converter has no torque of itself and is required to run at a synchronous speed corresponding to the line frequency and its own pole number, a small synchronous motor having the same number of poles is used to drive it.

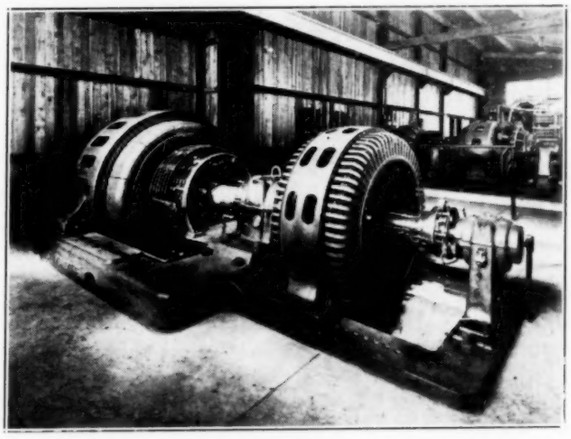


FIG. J—Frequency Converter Set. Note the synchronous auxiliary machine.

A given frequency converter will have a greater capacity when operated 6 phase than 3 phase, so usually for reasons of economy both ends of each phase of the secondary winding of the main motor and the armature windings of the synchronous machine and the converter are brought out so that the connections between them may be made for 6 phase operation, instead of the 3 phase connections shown.

The converter has a rotating armature which is substantially the same as that of the standard synchronous converter as is shown in the accompanying photograph.

The stator has no main pole windings and furnishes its own excitation but has compensating windings as do many D.C. machines for the improvement of commutation and the necessary magnet iron to confine the field flux to the proper path.

Principle of the Frequency Converter

The function of this machine is the conversion of the frequency applied to its slip rings to a different frequency at the commutator without affecting voltage. The manner in which it accomplishes this is best shown by comparing its operation to that of a synchronous converter. When a voltage at a given frequency is applied to the slip rings a magnetic field is set up which rotates about the armature at a speed corresponding to the line frequency and the machine pole number (thus 750 RPM for a 25 cycle source and 4 pole machine) just as the rotating primary field of an ordinary induction motor is set up by the primary winding. If now the rotor of this converter be driven by some outside agency but in a direction opposite to that of the field then the field will be stationary in

FIG. K—Complete Stator of Frequency Converter. Later types have interpoles, but no main field windings.

space and will be the equivalent of that in a synchronous converter set up by its D.C. excitation, the voltage appearing at the commutator will then be D.C. and the operation that of a synchronous converter. But if the machine be driven at 600 RPM which corresponds to a frequency of rotation of 20 cycles in the same direction as before the field set up by the armature con-

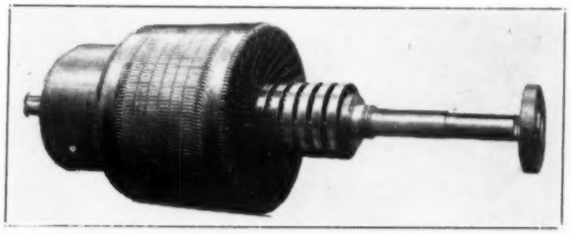


FIG. L—Armature of Frequency Converter. Note similarity to that of a synchronous converter.

ductors will rotate forward in the stator at 150 RPM which corresponds to a frequency of 5 cycles and the voltage appearing at the commutator will have this frequency of 5 cycles and will have the same value as that applied to the slip rings. Similarly if the frequency of rotation of the armature be 30 cycles (900 RPM) the voltage on the field will rotate backward

with a frequency of 5 cycle and the voltage on the commutator will have this same frequency but its relative direction will be reversed. Thus it is seen that the frequency on the commutator of this machine is the difference between that applied to its slip rings and that of its rotation.

Application of the Converter to this Drive

When the frequency converter described above is used as shown in Fig. 13 with its commutator connected to the induction motor secondary and its slip rings to the armature of the synchronous machine while it is driven mechanically by a small motor at a synchronous speed corresponding to line frequency and its pole number (for example 750 RPM for a 4 pole converter and a 25 cycle power system) it will for all speeds of the drive above or below synchronism convert the energy of the synchronous machine at its armature frequency to energy at the same frequency as that in the secondary of the main motor or convert that of the main motor secondary to the same frequency as that of the synchronous machine for an opposite flow of power. Fig. 14 shows the "why" of this operation. Let the line frequency "F" which is equal to the frequency of rotation "B" of the converter be represented by the length of the line so marked. If "s" be the slip of the main motor expressed as a fraction when the drive is running at any given speed below synchronism then the frequency in the main motor secondary will be (FxS) cycles. Since the synchronous machine is wound for the same pole number as the main motor its speed will now be the fraction (1-S) of synchronous speed and its frequency F (1-S) cycles which is impressed on the converter slip rings. The direction of rotation of the converter being properly chosen and its frequency of rotation B-F cycles, then the frequency which appears at its commutator is the difference between that applied to its slip rings F (1-S) cycles and F cycles which is [F-F (1-S)] = F-F + FS = FS cycles which is the same as that in the induction motor.

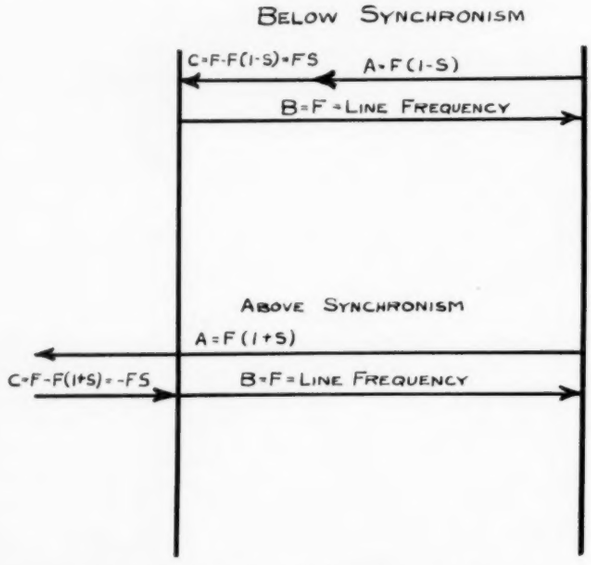


FIG. 14—Frequency Chart for Frequency Converter.

Let F = Line Frequency.
S = Slip of Main Motor Expressed as a Fraction.

A = Frequency of Synchronous Machine.
= Line Frequency—Slip Frequency.
B = Frequency of Rotation of Converter.
= Line Frequency.
C = Frequency at Commutator of Converter.
= A-B.

Similarly if the drive be running at a slip S above synchronism the power delivered by the synchronous machine to the converter slip rings will be at a frequency F (1+S) cycles and the frequency and direction of rotating B-F cycles of the converter being unchanged that appearing at its commutator will be the difference between the two [F-F (1+S)] = F-F-FS = -FS cycles. The minus sign indicates that this frequency has an opposite direction of rotation and it will be remembered that when the main motor is operating above synchronism its slip frequency is reversed because its secondary conductors are now rotating faster than the revolving field set up by the primary winding and cutting this field in an opposite direction. Thus the converter is seen to supply at its commutator the same frequency as that in the main motor secondary at all speeds.

Voltage Relations in Secondary Circuit—How Speed is Controlled

The voltage relations in the circuit composed of the main motor secondary, the frequency converter and the synchronous machine are as shown in Fig. 7 the voltage chart for both Kramer, Frequency Converter and Scherbius sets. If excitation be supplied the synchronous machine when the set is running light just below synchronism it will generate a voltage E_1 which is applied unchanged in value but at the proper frequency to the secondary of the main motor. This voltage is in a direction pre-determined to "buck" the generated secondary voltage E_m and the set slows down until a balance is reached where the difference between generated and impressed voltage is just sufficient to circulate the required load current. If the excitation be applied in the opposite direction the set will accelerate and go above synchronism and its speed for any given value of excitation will be stable and its change of speed with load only slightly greater than that of the main motor alone.

As described in the general statements relating to the flow of power between machines forming an AC adjustable speed set, the constant HP set provides an auxiliary machine mechanically connected to the main motor which acts as a motor when the drive is operating below synchronism and as generator when it is above. In this case it is the synchronous motor mounted on the main motor extended shaft and for speeds below synchronism it absorbs the electrical slip energy fed to it from the secondary of the main motor through the converter and delivers it as mechanical load torque while at speeds higher than main motor synchronous it absorbs a part of the load torque of the main motor and returns it as electrical energy through the converter to the main motor secondary. In either case the main motor is taking full rated electrical power from the lines and delivering rated load torque while full rated current circulates in its secondary windings. It is only the voltage and frequency of this secondary circuit that changes.

Set Operates Double Range—Rating of Auxiliaries

Since the losses of rotation of the converter are supplied direct from the power line and it is driven mechanically by a separate small motor there is no interruption to its ability to convert when the speed of the drive approaches synchronism. Therefore this set will carry its full rated load over any part of its speed range and will accelerate through synchronism with that load.

As in the case of the Kramer set the rating of the auxiliaries is determined by the amount of departure from synchronous speed. A 25% speed reduction or increase requires that the auxiliaries handle 25% of the HP rating of the set. A 10% reduction or increase will mean that the rating of the auxiliaries will be 10% of that of the set and a like proportion in other cases.

The possibility of double range operation considerably decreases the rating, size and, as a rule, the cost of the auxiliaries required for a given speed range from what they would be for the same set operated single range. Consider the case of a drive delivering 1000 HP over a speed range of 500 to 250 RPM. A single range set would have 500 HP auxiliaries and a 500 RPM main motor while a double range set would have 250 HP auxiliaries and a 375 RPM main motor. The speed of the main motor is lower for the double range set and therefore this motor is larger physically and presumably more expensive but its auxiliaries are only half the size of those for the single range set and since these comprise two machines of special construction the saving here more than over balances the increase in main motor size.

Power Factor Correction—Efficiency

To improve the normal power factor of the main motor it is necessary to advance slightly the phase angle of the power supplied its secondary from the auxiliaries. This may be accomplished by shifting the brush position on the converter or by a mechanical shift of the poles on the small motor driving the converter. Shifting the brush position is a matter involving commutation and therefore this setting cannot be left to the operator to adjust while if it is fixed once for all the amount of power factor correction obtained is also fixed.

In order to allow adjustment of the degree of correction obtained an electrical equivalent of the second method is used. This consists of using a distributed field winding on the small driving motor, which is split into two sections, each fed through a separate rheostat. These rheostats are mechanically connected and their resistance proportioned by test so that the total excitation remains constant while the current in one winding is decreased and that in the other simultaneously increased. The placing of the coils forming each winding is such that the axis of the consequent poles of the one is displaced slightly from that of the other and the movement of these rheostats then results in a shift in the pole position of this machine and a change in the amount of power factor correction the converter affords.

The necessity for correcting power factor involves an increase in the capacity of the converter while the amount of correction required is determined by the inherent power factor of the main induction motor. It is the usual practice to build into the converter sufficient capacity to permit keeping the overall power factor of the set at 90-95% or better for all loads.

The overall efficiency of the set is from 3 to 5% lower than that of the main motor alone at the maximum speed reductions because of the losses in the auxiliary machines, although the frequency converter drive shares the comparative advantage in efficiency of a double range system over a single range type as a result of the fact that its auxiliaries and the amount of power they handle are smaller for a given speed range. Fig. 15 shows typical power factor and efficiency curves for a frequency converter set, compared to that of the main motor alone.

Permissible Speed Range

The use of these sets is practically confined to 25 cycles and to relatively small speed ranges there, although some are in entirely satisfactory operation on 60 cycle systems. The limit on the speed range is a commercial one and is determined by the physical size which the converter must have to give good commutation at the maximum frequency on its commutator. Commutation is easier on a slow speed machine but

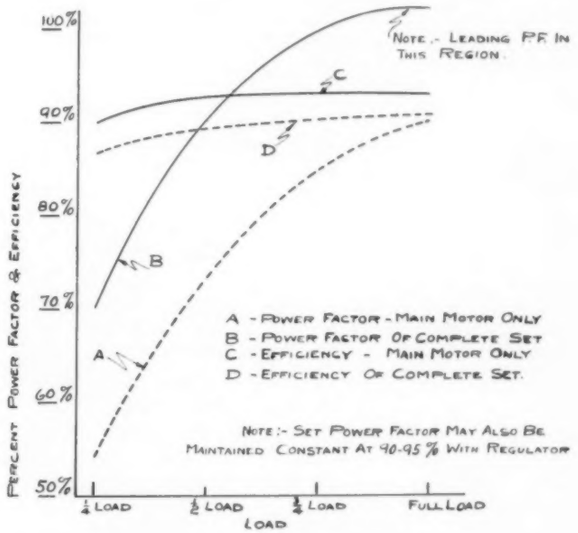


FIG. 15—Power Factor and Efficiency of Frequency Converter Set Constant HP. Type. Rating—800 HP. 220—187—150 RPM.

for the same rating a slow speed machine is larger and more expensive and has more poles and brush arms which also add to the cost. Also a 60 cycle machine for the same speed would have 2.4 times as many poles and sets of brushes as if it were to work on a 25 cycle system. These considerations combined with the fact that the practical limit of frequency on an AC commutator is in the neighborhood of 18-20 cycles and that the difficulties encountered increase directly with this frequency make the 60 cycle frequency converter set practically non-competitive and limit its range on 25 cycles to a variation of maximum to minimum speed of 1.67 to 1.

FREQUENCY CONVERTER SET—CONSTANT TORQUE TYPE

While there are several possible arrangements of equipment to make up a constant torque drive of this type, the one generally used is shown in Fig. 16. Here the converter is mounted direct on the extended shaft of the main motor and it, along with its transformer constitutes the only auxiliaries.

The converter proper is the same machine as is used for the constant HP type; its functions are essentially the same and it may be shown that if the converter has the same number of poles as the main motor it will properly convert the line frequency ap-

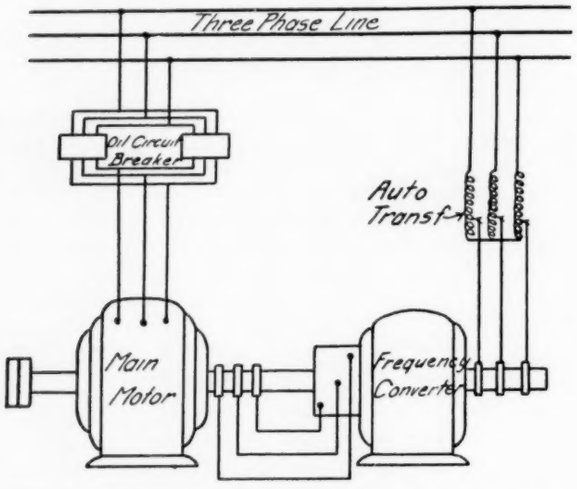


FIG. 16—Schematic Diagram Constant HP. Type Frequency Converter Set.

plied to its slip rings to the slip frequency of its main motor at all speeds. Thus for a line frequency F and a slip S on the main motor expressed as a fraction of line frequency the speed of the converter corresponds to a frequency F (1-S) while the frequency applied to its slip rings is always F. If the phase rotation of the connections to its slip rings be properly chosen the frequency of rotation will subtract from the applied frequency and that appearing at the commutator will be [F-F (1-S)] which is FS the slip ring frequency of the main motor. When the drive goes above synchronous speed the frequency of rotation of the converter becomes [F (1+S)] and the difference between this and line frequency F is now [F-F (1+S)] which is (-FS) indicating an opposite direction of rotation of the power on the converter commutator, which is again correct for connection to the main motor slip rings.

How Speed is Controlled

In common with other systems using dynamic control this set require an external EMF which being modified to the characteristics of the induction motor secondary is applied to this circuit in a direction to either oppose or assist its generated voltage and so control the main motor speed. Here the transformer supplies this external voltage direct from the line and taps on the secondary winding permit controlling it and the speed of the drive in several steps. A knife switch also allows for the reversal of the voltage when it is desired to run above synchronous.

Power Factor Correction—Efficiency

Power factor correction is obtained by the use of auxiliary windings on the transformer so interconnected with the main windings that the voltage across a phase of the converter is made up of two components, one of which is in phase with the corresponding phase of the line and one 60 degrees ahead of that phase. The effect of this arrangement is to advance the phase angle of the current in the entire secondary circuit and thus improve the power factor of the main motor. This method allows of no control of the amount of correction applied, but as a rule will allow the

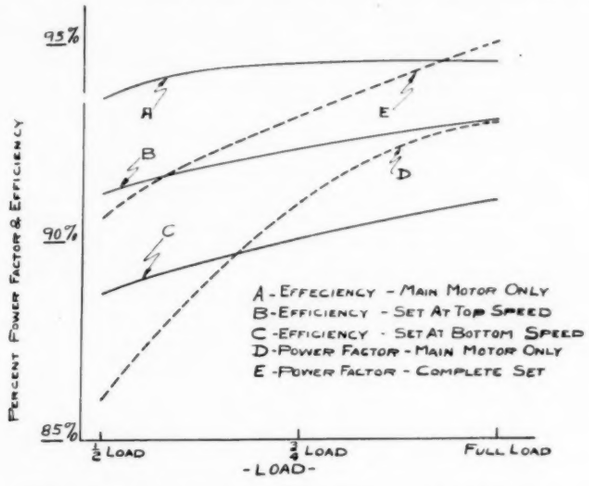


FIG. 17—Power Factor and Efficiency of Typical Frequency Converter Set. Constant Torque Type Rated 1760/1600/1440 HP.—550/500/450 RPM.

maintenance of an overall power factor for the set of 90% at any load and speed.

Since there are but two auxiliaries in this set, only one of which rotates and since the set operates double range and therefore these auxiliaries handle only half the amount of power those of a single range set would their losses might be expected to be small and the overall efficiency of the set high. This is indeed the case although it is lower than that of the main motor alone.

Fig. 17 shows the overall efficiency and power factor of such a set and the same quantities for the main motor alone, for comparison.

Rating of Auxiliaries—Set is Double Range

The rating of the auxiliaries is determined by the amount of speed reduction as is the general rule for dynamic controlled sets.

The capacity required of auxiliaries at a given speed is then approximately Load Horsepower $\times \frac{\text{Slip}}{(1 \pm \text{Slip})}$ using the plus sign for speeds above synchronism and the minus sign for speeds below. Thus for a 1000 HP drive having a constant torque rating of 1200/1000/800 HP at 720/600/580 RPM the power which the auxiliaries must handle is at the top speed approximately $1200 \times \frac{0.20}{(1 + 0.20)} = 200$ HP and at the bottom speed $800 \times \frac{0.20}{(1 - 0.20)} = 200$ HP. The rating required for the

same delivered load at intermediate speeds will be less in proportion as the speed reduction from synchronism is less so the auxiliaries used must have this maximum rating of 200 HP and will then be adequate for all other speeds within these extremes.

Since the converter is mechanically driven at all speeds and fed from the power line there is no interruption to its converting ability at synchronous speed and the set will deliver its full rated load at and near synchronysm and accelerate this load to higher speeds. The number of taps provided on the transformer limits the speed points available, of course, but these points may be located as desired within the range of the set.

Modifications of Constant Torque Sets

One modification of the arrangement already described is the simple substitution of an induction voltage regulator for the transformer feeding the slip rings of the converter. This makes available any desired voltage and consequently any speed within the specified range, but does not permit obtaining power factor correction in the same way. The correction affect is then obtained by shifting of brush arms on the converter commutator.

This voltage regulator which is not a regulator at all in this case, but simply a special kind of transformer arranged to allow shifting of the secondary winding with respect to the primary and thus control of the secondary voltage, is considerably more expensive than the plain transformer. The cost of a set so equipped is therefore somewhat greater and the only advantage is an increased number of speed points.

Another possible modification is the substitution of a motor generator set composed of two synchronous machines for the transformer. In this case one of these machines has a distributed field winding just as described for the small motor driving the converter of the constant HP type set and by manipulation of the rheostats in this field circuit the power factor of the set is controlled by varying the field of the other machine.

Such a set would include two more rotating machines than the original type and their cost and losses would make the set less economical to buy or operate. For this reason this modification has not been used on any drives built so far. Its only advantages are the possibility of control of power factor and of speed in as small steps as is desired.

SUMMARY OF CHARACTERISTICS, ADVANTAGES AND DISADVANTAGES OF FREQUENCY CONVERTER SETS

This summary is intended to include all features of construction and performance which are pertinent to their operation and most advantageous use, and they necessarily include both advantages and disadvantages as well as those qualities which are of value in one application and a detriment in another.

1. The set is built in either the constant HP or constant torque types, single or double range.

2. Since the frequency converter of the constant torque type and the auxiliary synchronous machine of the constant HP type each run at the speed of the main motor their size and cost will be affected by the synchronous speed of the drive, being greater for low speeds.

3. The use of these sets is confined to 25 cycle systems and small speed ranges.

Disadvantages

1. The frequency converter is a special machine and operators and repairmen would not be familiar with it.

2. The converter has an AC commutator. It will be noted that all the dynamic regulating sets include commutators, some AC and some DC. AC commutation is the more difficult and less desirable.

Advantages

1. The sets may operate double range and thus share the general advantages of any double range sets, which are:

a. The auxiliaries may be of much less capacity and size than for a single range set, having the same top and bottom speed.

b. Since a smaller amount of power goes through the auxiliaries their losses are smaller and the overall efficiency somewhat improved.

c. The unregulated speed of the main motor is at or near the center of the speed range and more products of the mill may be rolled without the auxiliaries. Thus a lighter section which is normally rolled at a high speed may be rolled at a lower speed but those normally rolled at a low speed cannot so easily be rolled at a higher speed. The unregulated speed of a single range set being at the top of its range only a few products may be handled without the auxiliaries or when they are under inspection or repair.

2. The constant torque type of set has only two auxiliary machines and one of these is a transformer. This makes for simplicity and good efficiency.

3. The amount of power factor correction may easily be subject to control of the operator and may be maintained better than 90-95% at any load or speed.

4. There is no gap in the speed range and full load may be carried at any speed.

PROVISION FOR FUTURE CONVERSION OF CONSTANT SPEED DRIVE TO FREQUENCY CONVERTER SET

If at the time that a constant speed induction motor drive is installed it is known or considered probable that speed regulating equipment will be added later, it is good economy to make certain provisions in the original drive to facilitate this later addition.

Beside the physical space for the location of the frequency converter for a constant torque type or the synchronous machine of a constant HP type there should be a shaft extension for coupling it to the main motor. The design, size and cost of the converter will be largely benefited if the open circuit standstill voltage across one phase of the main motor secondary is 360 volts or lower and if both ends of the secondary winding be brought out to slip rings for six phase operation of the auxiliaries.

SCHERBIUS SETS

The third of the widely used types of AC speed regulating equipments for Induction Motors is the Scherbius set, first developed and used in Europe and now widely used in the United States. It is sold, guaranteed and operated double range.

The means by which it operates to regulate the speed of a wound rotor motor below or above synchronism are fundamentally the same as those described for the Kramer and Freqency converter sets. Auxiliary apparatus supplies a voltage at slip frequency to the secondary of the main motor which opposes the induced secondary voltage and causes the motor to slow down until the difference between the induced and impressed voltage is sufficient to circulate the required load current. The value of this impressed voltage may be varied or it may be reversed in direction. Its value determines the variation of speed from synchronism and if it be reversed the main motor will go above synchronism where again the value of this applied voltage determines the speed at which the drive will run. The speed for a given voltage is practically constant, the speed variation from full load to no load being only slightly greater than that of the main motor alone, although where desirable it may be increased. The drive will deliver its full capacity over any part of its speed range including that part close to and at synchronism.

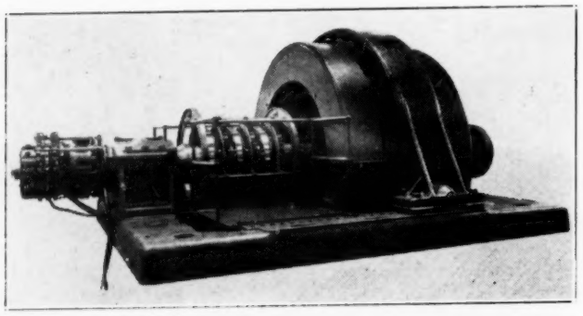


FIG. M—Main Induction Motor of Double Range Scherbius Set showing Ohmic Drop Exciter. Note the small size of the exciter.

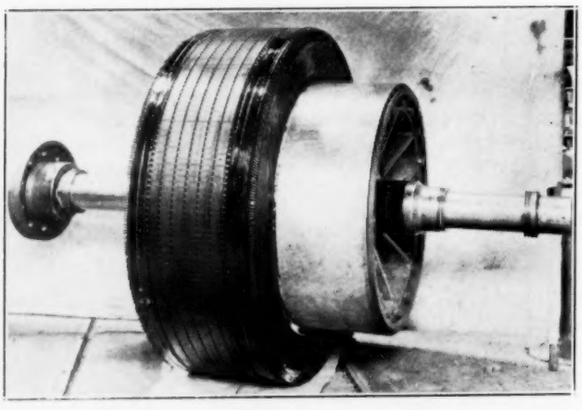


FIG. N—Armature of Scherbius AC. Regulating Machine. Note similarity to DC. Armature.

CONSTANT TORQUE TYPE

These sets are always supplied as the constant torque type, whether the application be for a constant torque or a constant HP drive. When the rating is to be constant HP the set is under rated at the higher speeds, but since the drive includes means for power factor correction this imposes no hardship upon the purchaser and the additional capacity may prove useful. The reason for this policy is the higher cost of manufacture of the constant HP type as will be explained later.

The complete set is made up of a standard wound rotor induction motor having a small machine called an Ohmic Drop Exciter mounted on its extended shaft and an auxiliary MG set composed of a standard squirrel cage induction motor and a 3 phase AC commutator machine which may operate as a generator or drive the squirrel cage machine as a motor.

Fig. 18 indicates the connections of these machines.

The 3 sets of brushes of the AC commutator machine are connected directly to the slip rings of the main motor while the squirrel cage motor is connected to the power line thus providing a means of returning excess secondary energy of the main motor to the line for speeds below synchronysm and obtaining necessary additional power for speeds above synchronism.

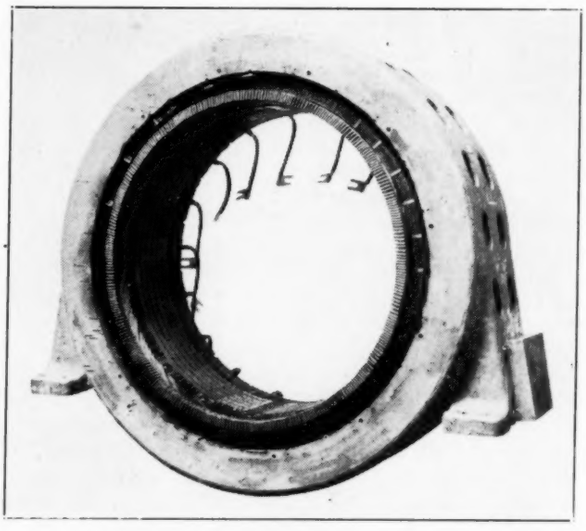


FIG. O—Stator of Scherbius AC. Regulating Machine.

The AC commutator machine has its main field excited in part from the slip rings of the main motor through an auto transformer and in part from the Ohmic Drop Exciter which in turn takes its power from the line.

Speed control is affected by changing the percentage of the main motor secondary voltage applied to this field and thus controlling the generated voltage of the machine and power factor correction obtained by changing the phase angle of the field current with a small transformer winding and thus advancing that of the AC commutator machine voltage.

The AC Commutator Machine

As shown in the accompanying photographs the rotor of the AC commutator machine is very similar to that of a DC machine. The stator carries three field windings: The main field winding of the shunt type, a shunt wound interpole field, and a series compensating winding inserted in the pole faces to offset the effect of armature reaction. This last is exactly the same as that of a mill type DC machine

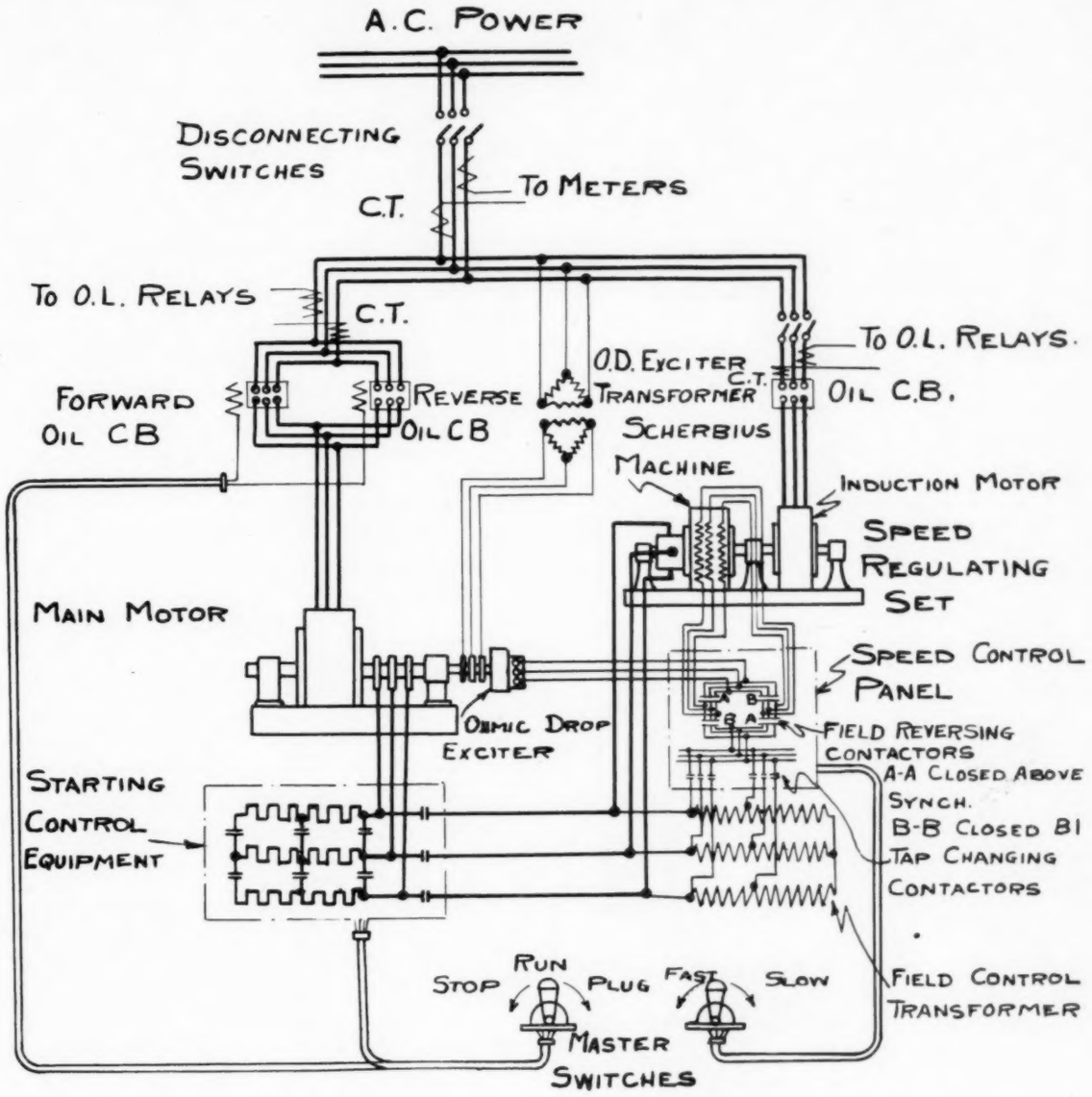


FIG. 18—Schematic Diagram Double Range Scherbius Set Constant Torque Type.

and has the same effect of bettering commutation on widely and rapidly varying loads.

A standard DC generator of course normally has direct current excitation and produces a direct current voltage, but if it be excited with a certain A.C. frequent it will produce a voltage of that same frequency. Similarly this AC commutator machine is excited from the secondary of the main motor and produces a voltage which is always of that same frequency. It may be shown also that where the Ohmic Drop Exciter is used to furnish a part of this excitation that furnished by it is likewise always of the same frequency as the main motor secondary.

The Ohmic Drop Exciter

When the set is to operate double range this machine is included to furnish excitation for the AC commutator machines because when the set is operating close to and at synchronism the secondary voltage of the main motor and consequently the excitation from this source is practically zero. It is not included in a single range drive. It is exactly the same machine as the Frequency Converter already described as a part of the set so named.

It has an armature similar to that of a synchronous converter with three slip rings on one end and a commutator on the other. There is no stator winding and in fact no stator in the ordinary sense. This is replaced by a ring of magnetic material which serves as a keeper to confine the field flux to its proper path and is clamped to the rotor outside the windings and rotates with it. This construction and the mounting of the exciter is also shown in the accompanying photograph.

The exciter is mounted directly on the extended shaft of the main motor and its slip rings fed from

the power line through a small transformer. It has the same number of poles as the main motor and consequently always the same frequency of rotation —Thus 20 cycles for both if they are 6 pole machines and are running at 400 RPM, 15 cycles at 300 RPM and so on.

It is the particular function of this machine to provide a given constant voltage at a frequency which is always the same as that of the main motor secondary, whatever the speed of the set. It remains to show how this is accomplished.

When the armature of the exciter is energized from its slip rings a magnetic field is set up which rotates at synchronous speed of 500 RPM say for a six pole machine on a 25 cycle system, just as the rotating primary field of an induction motor is set up by its primary winding. If now the exciter be mechanically rotated in the opposite direction at 500 RPM this field will be stationary in space and will be the equivalent of that of a synchronous converter set up by its DC excitation. The voltage appearing at its commutator will then be DC and the operation that of a synchronous converter. But if the machine be driven only 400 RPM in that direction, which corresponds to a frequency of rotation of 20 cycles

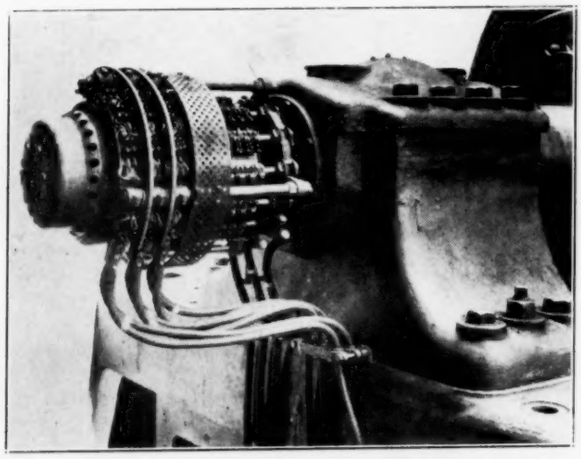


FIG. P—Ohmic Drop Exciter mounted on extended shaft of main motor of Scherbius Set. Note the commutator and slip rings.

the field set up by the armature conductors will rotate backward 100 RPM which corresponds to a frequency of rotation of 5 cycles and this frequency will appear at the commutator.

Since the exciter is driven by the main motor of the set having also 6 poles its slip at this speed will be 500-400 = 20% and its secondary or slip frequency will be $\frac{100 \times 25}{500} = 5$ cycles. Similarly for a speed of 300 RPM the field of the exciter will have a frequency of rotation of 10 cycles and it will produce a voltage of this frequency at its commutator, while the slip frequency of the main motor will also be $\frac{500\text{-}300}{500} \times 25 = 10$ cycles.

Again when the exciter is driven 600 RPM the field will rotate 100 RPM in space, but in the opposite direction from that which it moved before and 5 cycles will appear at its commutator as before, but having an opposite direction. The secondary frequency of the main motor at this speed will also be $\frac{500\text{-}600}{500} \times 25 = 5$ cycles and since the secondary conductors which produce this voltage are now moving faster than the primary field they cut it in an opposite direction and the secondary frequency will likewise be reversed in direction. When the set runs at synchronous speed, 500 RPM say, the field of the exciter is stationary and its rotor bars are therefore cutting this field at synchronous speed. When the set runs at 400 RPM in one direction the exciter field is moving 100 RPM in the opposite direction, so that the rate of cutting of this field by the armature bars is again 500 RPM. Similarly when the speed of the set is 600 RPM that of the field is 100 RPM in the same direction and the rate of motion of the exciter armature bars with respect to its field still 500 RPM. Therefore since the intensity of the field does not change we may expect the voltage appearing at the commutator of this exciter to be the same at all speeds and it actually is.

How Excitation Is Obtained

Fig. 18 shows that the field of the AC commutator machine is excited both from the Ohmic Drop Exciter and from the main motor slip rings through an auto transformer. When the speed of the set is widely different from synchronism the portion of the excitation furnished by the O.D. Exciter is small compared to that from the auto transformer, while at and close to synchronous speed there is practically no secondary voltage on the main motor and all the excitation is derived from the O.D. Exciter. The auto transformer furnishes the voltage necessary to overcome the reactive drop in the field circuit and at speeds widely removed from synchronism this is the greater part of the total, because the frequency in the main motor secondary is then comparatively high. The O.D. Exciter furnishes the constant voltage required to overcome the Ohmic Drop in this circuit and since the frequency is practically zero near synchronous speeds the reactive drop is likewise almost zero then and only the Ohmic Drop remains to be overcome.

The small variations in main motor secondary voltage for a given speed and field setting occurring with changes of load are accompanied by corresponding changes of frequency so that the tendency is to maintain a constant field flux in the AC commutator machine.

Changes in the field strength of this machine and thus of the speed of the set are accomplished by changing the taps on the auto transformer so that a given secondary voltage of the main motor will impress a higher or lower voltage on this field. The controller provided also changes the amount of external resistance between the O.C. exciter and the field to keep the Ohmic Drop constant with varying field current.

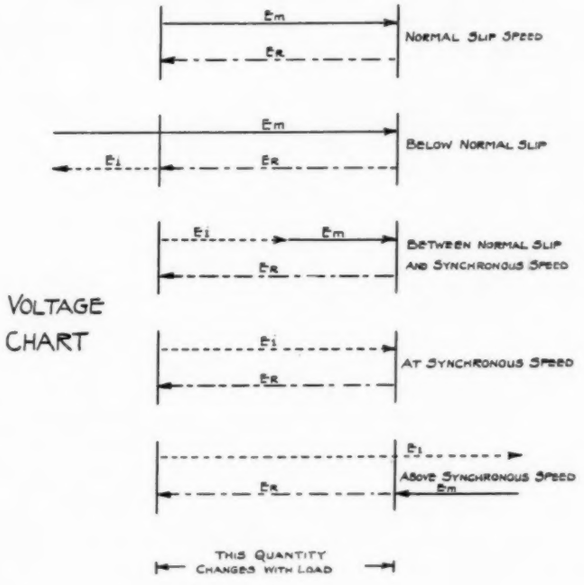
The O.D. Exciter is not used on a set which is to operate single range only as it is unnecessary. In this case the total excitation comes from the auto transformer.

Operation of Complete Set

The voltage relations in the circuit composed of

the main motor secondary and the AC commutator machine are as shown in Fig. 7 a voltage chart for both Kramer, Frequency Converter, and Scherbius sets. If excitation be applied to the AC commutator machine from the auto transformer and O.D. Exciter when the set is running light just below synchronism it will generate a voltage E_i which is applied to the secondary of the main motor in a direction predetermined to "buck" the generated secondary voltage E_m and the set slows down until a balance is reached where the difference E_r between generated and impressed voltage is just sufficient to circulate the required load current. If this excitation be applied in the opposite direction the set will accelerate and go above synchronism. Its speed for any value of excitation will be stable and the change of speed with load only slightly greater than that of the main motor alone.

As described in the general statements relating to the flow of power between machines forming an AC adjustable speed set the constant torque type has



Em—Slip voltage of motor secondary (This reverses as motor passes through synchronism.

Er—Voltage required to circulate a given load current through motor secondary winding.

Ei—Voltage supplied by auxiliaries and impressed upon secondary.

FIG. 7—Voltage relations in secondary circuit of the Main Motor of an A. C. Adjustable Speed Set.

the main motor only delivering power to the load and auxiliaries connecting the secondary of the main motor to the power line. When the set is delivering its rated torque to the load at speeds below synchronism the main motor takes its full HP rating in electrical energy from the line, but since it must deliver more than this in mechanical output the difference must be furnished as electrical energy to the main motor secondary. For the Scherbius constant torque type set the M-G set composed of the squirrel cage machine and the AC commutator machine serve to convert this surplus energy to the proper characteristics and feed it back into the line in the first case and to supply it from the line at proper frequency and voltage in the second.

Rating of Auxiliaries

The rating of the regulating set is determined by the amount by which the speed of the main motor is varied from synchronous and by the HP which the drive requires at the extreme speeds.

The electrical energy to be handled by the regulating set at any given per cent slip of the main motor is approximately $\frac{\text{slip} \times}{1 + \text{slip}}$ shaft HP, considering the slip to be positive for speeds above synchronous and negative for speeds below. Thus a drive which is rated 1000/1000/1000 HP at 750/600/450 RPM will require at the top speed a regulating set to handle 25/125 x 1000 = 200 HP and at the low speed to handle 25/75 x 1000 = 333 HP. The rating at the low speed will of course determine the capacity required of the regulating set for this drive.

If the drive be rated constant torque 1250/1000/750 HP at 750/600/450 RPM the regulating set will have to handle 25/125 × 1250 = 250 HP and 25/75 × 750 = 250 HP at the high and low speeds respectively.

Double Range Drives

Scherbius sets are sold, guaranteed and operated double range. When equipped with the O.D. Exciter they will carry full load through synchronism to speeds above and their operation in this region is entirely stable.

The frequency and voltage in the circuit composed of the main motor secondary and the AC commutator machine becomes quite low in this region and is in fact theoretically zero at synchronism so the field of the AC commutator machine cannot receive the necessary excitation from the auto transformer which normally feeds it from this source. The voltage produced by the O.D. Exciter, while always of the same frequency as that of the AC commutator machine and the main motor secondary is constant in value for all speeds and is available at this point to furnish the necessary excitation. The amount which it furnishes is controlled by the insertion of varying amounts of resistance between it and the field it excites and thus the speed of the set controlled over this part of its range.

Operating a drive double range reduces the sizes of the regulating set from what it would be if the same drive had to cover this same speed range with a single reduction from a synchronous speed at its upper limit and the closer the synchronous speed of the double range drive comes to the center of the range required the smaller the regulating set.

Thus consider the case of a drive which requires 5000/500 HP over a range of 300/150 RPM. Single range equipment would require a regulating set to handle 50/50 x 500 = 500 HP while if the set can be given a synchronous speed of 214 RPM the regulating set need handle only 40/140 x 1000 = 285 HP at the high speed and 30/70 x 500 = 214 HP at the minimum speed.

If now a synchronous speed of 250 RPM be chosen the regulating set must handle 20/120 x 1000

= 167 HP at the maximum speed but 40/60 x 500= 333 HP at the minimum speed. The capacity required in the regulating sets will be 500; 285; 333 HP, respectively, in the three cases cited. The second arrangement which puts the synchronous speed of the set approximately midway of the speed range gives the minimum size regulating set. It will be noted that in the first case the speed of the main motor is higher (300 RPM) than in the second (214 RPM) and it would therefore be a smaller and less expensive machine, but as a rule the difference in the size of the regulating set more than offsets this and the net result is that the choice of synchronous speed nearest the center of the speed range will give the most economical drive.

If the drive is to deliver constant HP the main motor will have approximately the same size, whatever the choice of its synchronous speed and since there is then nothing to offset the increase in size of regulating set it is particularly important to have the main motor synchronous speed near the center of the speed range.

Constant Torque Type Sets Delivering Constant HP

If the set be of the constant torque type and yet must deliver constant HP then the main motor must be larger for the same output than if the set were of the constant HP type and the whole set is then under rated at the higher speeds but since power factor corrective effect is included with the set this is no hardship to the purchaser and the extra capacity is there if needed.

Thus if a given drive requires 1000 HP, 300 to 150 RPM, the main motor of a constant HP type set to supply it would be 1000 HP at 300 RPM and at 150 RPM it and the auxiliary motor coupled to its shaft would each deliver half the load torque, but the main motor of a constant torque type set must deliver this full torque by itself and to do this it must have a rating of 2000 HP at 300 RPM.

The whole of the constant torque type set then has a torque capacity over its entire speed range equal to the maximum required by the constant HP rating and it is operated below this at the higher speeds. The reason for this policy of using constant torque sets for both those and constant HP drives is that this type lends itself better to manufacturing practices and can therefore be produced more economically than the other. The regulating machine of a constant HP type set being operated at main motor speed must be built different for each such drive, and its size largely influenced by the speed of the drive. The regulating set of the constant torque type is mechanically independent of the main drive so that the same standard set may be used for many different drives and built to operate at the most economical speed so that in spite of its including two machines instead of one for a constant HP type its average total cost is lower.

Permissible Speed Range

The limiting factor in determining the maximum possible speed range of these sets is the commutation of the AC regulation machine. This becomes more difficult as the frequency on the machine increases and the practical limit is set at 20 cycles.

The size and, consequently, the cost of the regulating set increases directly with the speed range, other things being equal and this is often a limit on the range employed even though it is feasible to build a set which will operate entirely satisfactorily on a wider range.

The frequency on the regulating set is higher for a given speed range when the power supply is 60 cycles than when it is 25 cycles and the result is that 60 cycle Scherbius sets are limited in range to 2 to 1, while 25 cycle sets are limited only by the cost of the regulating set. Thus using 20 cycles of slip as a limit we can operate a 60 cycle set at speeds corresponding to 40 cycles lower limit and 80 cycles upper limit, obtaining a range of 80:40 = 2:1, while the same 20 cycles slip for a 25 cycle set would mean a speed corresponding to a lower limit of frequency of 25-20 = 5 cycles and an upper limit of 25 + 20 = 45 cycles, which is a range of 45:5 = 9:1. But, assuming a constant torque rating the capacity of the regulating set in the first case would be the same as that of the main motor and in the second case four times that of the main motor and since the special construction of the regulating machine makes it even more expensive per KW than the standard induction motor it is not economical to build these sets for such ranges. The usual limit is a total range of 3:1 obtained by regulating 50% each way from synchronous.

Efficiency and Power Factor

Means are provided in the set for maintaining an overall power factor of either 90 to 100% or 95 to 100% lagging for all loads and speeds according to the desires of the purchaser. This consists of a small transformer winding so connected as to advance the phase angle of the current supplied from the AC regulating machine and thus offset in part the lagging component of the primary current in the main motor required to maintain its magnetic field.

The cost per KVA of the AC regulating machine is much higher than that of standard synchronous machinery and it is not economical to try to include sufficient corrective effect in this machine to give the set a leading power factor, because of the increased capacity required in this machine to do this.

Fig. 19 shows the power factor and efficiency of a typical set as well as the same quantities for the main motor alone. These show that the power factor of the main motor is bettered by the addition of regulating equipment by reason of the corrective effect which they include and the efficiency lowered by reason of losses in the added machines. The overall efficiency of the set is of course lower than that of the main motor alone because of the losses

in regulating machines, and since on wide speed ranges a greater proportion of the total power is handled by the regulating machines, its efficiency is then comparatively less when operating at a speed far removed from synchronism than when closer. The inherent efficiency of the main motor alone also influences that of the set of which it is a part.

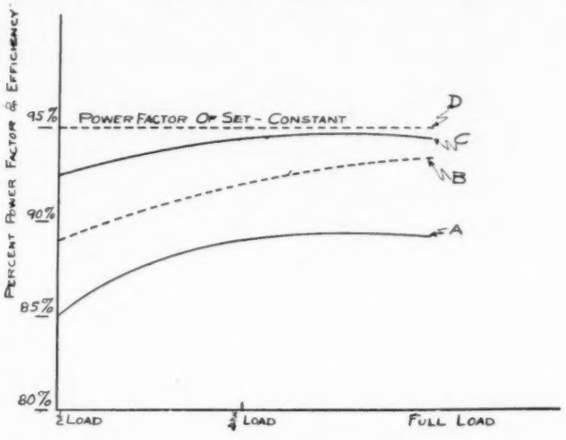


FIG. 19—Power Factor and Efficiency Curves of Scherbius Set and of Main Motor Alone. Set Rating—4500 HP., 498/375/311 RPM.

A—Efficiency of Set—Maximum Speed Reduction.
B—Power Factor of Main Motor Alone.
C—Efficiency of Main Motor Alone.
D—Power Factor of Set.

PROVISION FOR LATER ADDITION OF SCHERBIUS REGULATING EQUIPMENT TO A CONSTANT SPEED DRIVE

Sometimes it is known when a constant speed induction motor drive is installed that it will be necessary to add speed regulating equipment to it later and it then becomes important to know what provisions must be made in the constant speed drive for these additions.

Scherbius double range equipment will require a shaft extension on the end of the main motor to carry the OD exciter, and to get the most economical design of AC commutator machine the open circuit voltage of the main motor secondary across one phase when the rotor is standing still, known as the "locked" open circuit secondary voltage, should approximate 1,000 volts. Space must be provided in the vicinity for the regulating set in order to keep the voltage drop low in the leads between it and the main motor.

Constant Horsepower Type

While the constant HP type Scherbius set is not manufactured because it has inherent cost disadvantages when compared to the constant torque type, it is a perfectly feasible system which has been tested out and when the application requires constant HP it has the advantage of working both machines at their full rating and of including one less machine per drive than the constant torque set.

This set may be built for either single or double range and when built for double range it will carry full load close to and at synchronism and accelerate full load through this point to higher speeds. It includes the same power factor correction effect as the constant torque type and has similar operating characteristics.

Fig. 20 shows the main connection of a constant HP set. It consists simply of a standard wound rotor induction motor and mounted on the same shaft or coupled to it an AC commutator type regulating machine of exactly the same type as forms a part of the constant torque set. If the set is to regulate both ways from synchronous an OD exciter is used and also driven from the main motor.

As is the case with the constant torque set the excitation for the AC regulating machine is obtained through an auto transformer from the secondary voltage of the main motor and from the OD exciter when it is used, and since the frequency of its excitation is always that of the main motor secondary the voltage which it produces must likewise be the same and therefore may be applied to the secondary circuit.

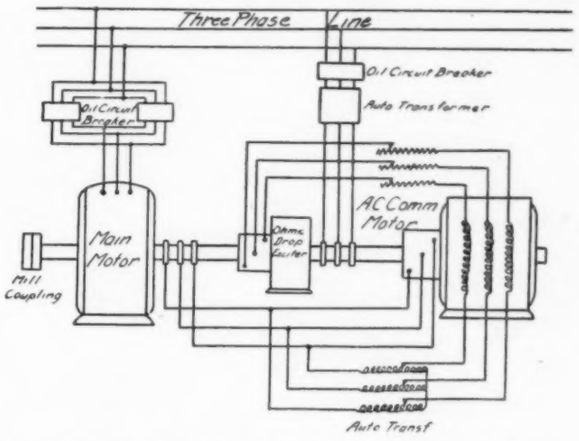


FIG. 20—Schematic Diagram of Double Range Scherbius Set Constant HP. Type.

Speed variation is obtained here just as it is on the constant torque type. By controlling the excitation of the AC regulating machine a given voltage is introduced in the main motor secondary in a direction to "buck" the voltage generated there and the machine slows down until the difference between the generated and the applied voltage is sufficient to circulate the required load current. Similarly excitation applied to the field of the regulating machine in the opposite direction causes the set to increase in speed above synchronous. The speed is practically constant for a given value of excitation and the operation stable at any speed within the range for which it was built.

The great difference between this and the constant torque set lies in the rating for a given constant HP load of the machines which make it up. The main motor of this set always takes its full rated HP in electrical energy from the line when the mill demands full load and delivers its rated torque to the load, which of course would not amount to constant HP at speeds below synchronism. The remainder of the torque necessary for a constant HP load is furnished by the AC regulating machine.

Therefore for a set delivering say 1000 HP at 25% slip the main motor simply has a rating of 1000 HP at the top speed and the AC regulating

machine a rating of 1000 x .25 = 250 HP. A constant torque set to deliver the same load must have a main motor capable of delivering the entire load torque which requires this machine to have a rating of 1000/75 = 1333 HP while the regulating set must have a capacity of $\frac{\text{slip}}{1 - \text{slip}}$ x shaft HP which is $\frac{25}{1 - 25}$ x 1000 = 333 HP.

In spite of the obvious gain in capacity of machines indicated it is the experience of the manufacturer that it is cheaper to build the constant torque type set for both constant torque and constant HP drives and it is his practice to do so.

The reasons for this as previously given are as follows:

1. The regulating machine of a constant HP set runs at the same speed as the main motor and its size and cost is thereby influenced by the main motor speed being greater for slow speed drives. A slow speed regulating machine also means a greater number of main and interpoles and brush sets which increases cost and is mechanically undesirable. The regulating machine would have to be designed anew for the particular speed and capacity of almost every drive built which adds to the expense of building them.

2. The regulating set of a constant torque set may have its speed chosen to best suit its design, independent of that of the main motor and thus a relatively few standard regulating sets used for many different drives.

SUMMARY OF CHARACTERISTICS, ADVANTAGES AND DISADVANTAGES OF SCHERBIUS SETS

This summary of characteristics of Scherbius sets is intended to include all features of construction and performance which are pertinent to their operation and most advantageous use, and necessarily includes both advantages and disadvantages as well as those qualities which may be of value in one application and a detriment in another.

1. The Scherbius system has been in use for more than twelve years in this country and a large number of drives have been put into operation during that time with satisfactory results.

2. The set has been built in the constant torque type only, but for either constant torque or constant HP service.

3. The size and cost of auxiliaries is independent of the synchronous speed of the drive.

4. Scherbius sets are built, sold, and operated both 25 and 60 cycle and at intermediate frequencies. The size and cost of the regulating machines for a 60 cycle drive is greater than that for a 25 cycle set because the frequency on the commutator for a given per cent speed regulation is higher, but as built they are entirely satisfactory on either frequency.

5. The maximum speed range available is 2:1 on 60 cycle system and five or six to one on 25 cycles. The practical limit as fixed by cost is usually less in either case.

Disadvantages

1. The regulating machine as well as the OD exciter has an AC commutator. While all dynamic regulating sets include commutators some AC and some DC, AC commutation is the more difficult and less desirable.

2. Both the OD exciter and the regulating machines are special machines and operators and repairmen would not be familiar with them..

Advantages

1. The sets may be operated double range and thus obtain the general advantages of any double range sets which are:

a. The auxiliaries may be of much less capacity and size than for a single range set having the same top and bottom speed.

b. Since a smaller amount of power goes through the auxiliaries their losses are smaller and the overall efficiency of the set somewhat improved.

c. The unregulated speed of the main motor is at or near the center of the speed range and more products of the mill may be rolled without the auxiliaries. Thus a heavier section which is normally rolled at a low speed cannot so easily be rolled at a higher speed. The unregulated speed of a single range set being at the top of its range only a few products may be handled when the auxiliaries are undergoing inspection or repair.

2. Scherbius sets are sold, guaranteed and operated single or double range. There is no gap in the speed range of double range sets and full load may be handled at any speed.

3. The overall power factor is maintained better than 90-95% at all speeds and loads.

4. No DC excitation is required and all power may be drawn from one source. This is an advantage in that where a drive is dependent upon two different sources of power trouble with either will shut it down.

NOTES TO TABLE III

The purpose of this table is:

(1) To present the essential information about each of the three systems of speed regulation which an engineer requires when first contemplating the use of one of them, and to present it in such form that he may make use of it without going through the detailed description of each set.

(2) To provide for the engineer already familiar with them a review of the advantages and disadvantages of each together with those characteristics which are an advantage in one application and a detriment in another.

Figures given have been checked with the manufacturers of the equipment to which they apply and represent present practice accurately although it is entirely probable that future development of the art will better the characteristics given, extend speed ranges or allow of economical construction in ways not now feasible.

TABLE III—SUMMARY AND COMPARISON OF KRAMER—SCHERBIUS—FREQUENCY CONVERTER SYSTEMS

	KRAMER	SCHERBIUS	FREQUENCY CONVERTERS
FREQUENCY	Best adapted to 60 cycle systems both from first cost and operating standpoint, although some 25 cycle sets are used.	Available for either 25 or 60 cycle service.	Built for 25 cycle operation only, although some sets are in operation on 60 cycles it is not economical to build them for that frequency.
POWER FACTOR	3 to 5% higher than that of the main motor alone.	Maintained at 90-95% or higher, but not subject to adjustment.	Maintained 90-95% or better and subject to some adjustment.
EFFICIENCY	The efficiency on all three types of sets will run about 3 to 5% lower than that of the main motor alone.		
SPEED REGULATION	The speed regulation on all three types will run 1 or 2% greater than that of main motor alone.		
MILL SPEEDS	Best adapted to high speed drives, from first cost standpoint, because part of auxiliaries run at same speed as main motor and their size and cost increases with lowered speeds.	Equally adapted to either high or low speeds because only one small auxiliary machine runs at main motor speed.	Best adapted to high speed drives because part of auxiliaries run at main motor speed and their cost is increased largely as their speed decreases.
CONSTANT TORQUE OR CONSTANT HORSEPOWER	Best suited to constant Horsepower drives. Practically always supplied in the constant HP type because this is the more economical to build, but used on either constant HP or constant torque drives.	Built only in the constant torque type because this type is cheaper to manufacture, but available for either constant HP or constant torque drives.	Built in either the constant horsepower or constant torque types.
SINGLE OR DOUBLE RANGE	Sold for single range operation only, although some are in double range operation. Will not carry load at speeds within 2-3% of synchronism or accelerate load through synchronism.	Built for either single or double range operation.	Built for either single or double range operation.
SPEED RANGE	Practical limit about 30-40% reduction from synchronism, fixed by economical considerations, although may go to 50%.	Usual limiting range about 2:1 as fixed by cost, but maximum is about 2:1 on 60 cycles and 5:1 on 25 cycles.	Available for small ranges only of the order of 10-15% variation each way from synchronous speed.
DISADVANTAGES	(1) Single range operation only. (2) Will not carry full load close to synchronism.	(1) Includes special machines with which operators and repairmen are not familiar. (2) Includes alternating current commutator.	(1) Includes a special machine with which operators and repairmen are not familiar. (2) Includes an alternating current commutator. (3) Small speed range only available.
ADVANTAGES	(1) Made up of standard machines with which the operators and repairmen are familiar. (2) Commutating machine operates on direct current.	(1) Wide speed range available. (2) Will carry full load close to and at synchronism and accelerate full load through synchronism. (3) Sets available for single or double range operation. Double range operation allows the use of smaller auxiliaries; reduces the amount of power which the auxiliaries must handle and thus improves efficiency, and by locating the unregulated speed of the main motor in the center of the range permits rolling a greater proportion of the mill products without the auxiliaries.	(1) Will carry full load close to and at synchronism and accelerate full load through synchronism. (2) Sets are available for double or single range operation, and when operated double range allow the use of smaller auxiliaries, reduce the amount of power which the auxiliaries must handle and thus improve efficiency, and by locating the unregulated speed of the main motor in the center of the range permit rolling a greater proportion of the mill products without the auxiliaries.

BRUSH SHIFTING MOTOR

This is a polyphase AC motor providing a truly adjustable speed over a wide range without auxiliary apparatus. A great many have been built in sizes up to 75 HP for auxiliary service and two of 500 and 600 HP respectively for rolling mill drive.

The speed once set changes with load only slightly more than that of a standard induction motor, but is easily varied when necessary and the machine while inherently a constant torque device will be stable in operation and deliver its full torque at any speed.

In view of these facts and the possibilities of its application to small mills it seems worth while to discuss it briefly and to set forth its characteristics of operation.

Fig. 21 shows the main connections of the machine and their relation to each other, while the accompanying photograph shows the general appearance of the finished machine.

Essentially the machine is a wound rotor induction machine with a third winding which through the medium of a commutator and the shifting of brushes on that commutator produces an adjustable voltage at slip frequency. This regulating voltage is controllable and reversible and when impressed upon the motor secondary winding it opposes or assists the internal secondary voltage and reduces or increases the motor speed from synchronous just as is done in a Scherbius or Kramer set.

The primary is wound on the rotor and fed from the line through slip rings, while the secondary winding is in the stator and has both ends of each phase brought out. In the same slots as the primary winding but not connected to it electrically, is the regulating winding which is brought out and connected to a commutator just as a DC winding would be. The two ends of each phase of the secondary winding are connected to brush yokes on opposite ends of the commutator, so that when the two sets of brushes are lined up each phase is short circuited by a commutator bar and the machine then behaves like a standard induction machine. To obtain speed adjustment the brush yokes are moved so that the brushes connected to the two ends of a phase of the secondary are several bars apart. Then when the primary is connected to the line its magnetic field induces a certain voltage in the regulating winding which through the action of the commutator appears at the brushes at slip frequency which is also that of the motor secondary and being impressed upon the secondary winding opposes its induced voltage and the motor slows down until the difference between induced and impressed voltage is enough to circulate the required load current.

By moving the brushes so that those connected to the two ends of a given phase are farther apart the voltage between them is increased and the motor speed still further reduced, or by moving the two apart in the opposite direction this voltage is reversed and assists the induced voltage in the secondary winding so that the motor speed goes above synchronism.

The speed at any load is stable and the change of speed with load is only slightly greater than that of a standard wound rotor machine.

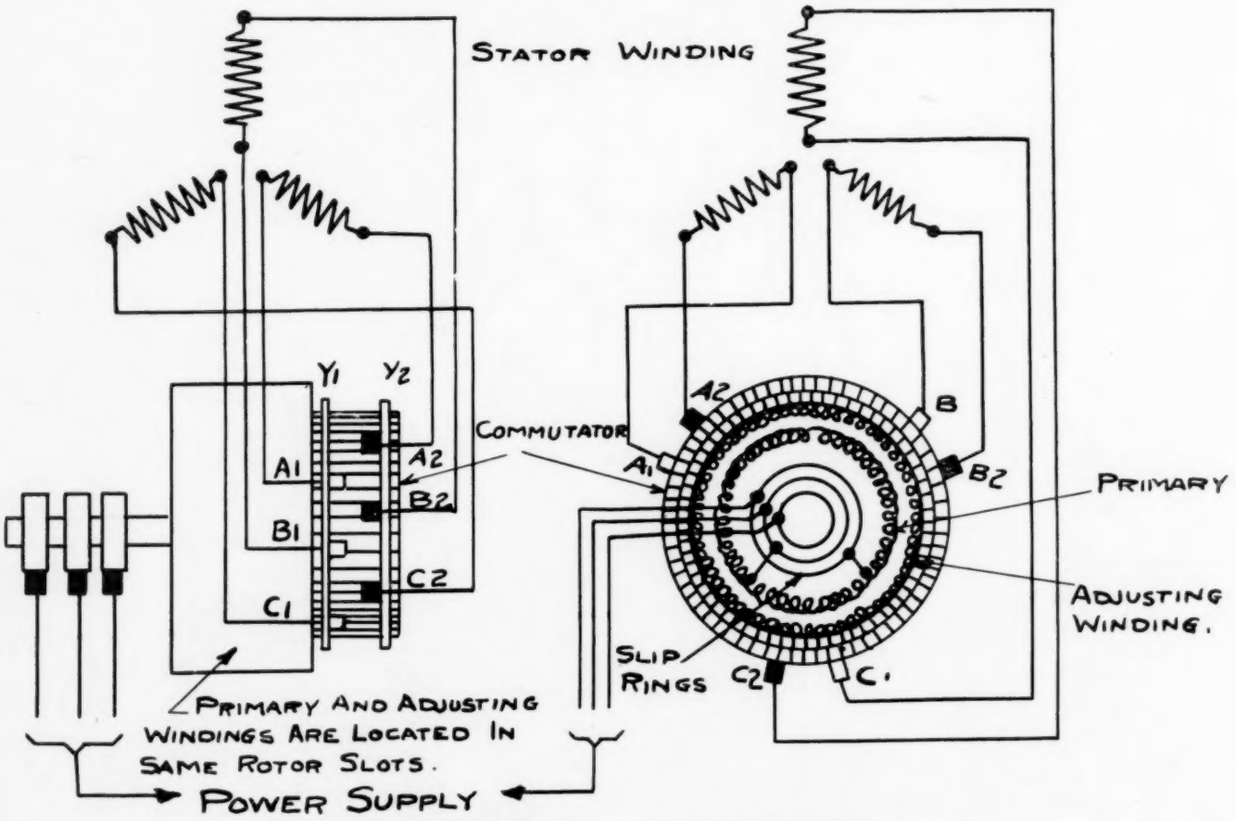


FIG. 21—Variable Speed AC. Brush Shifting Motor.

Control

The machine is normally started by being thrown directly across the line with the brushes in the slow speed position and when so handled will deliver about 200 per cent of full load torque while taking about 150-175 per cent full load current from the line.

The speed is controlled by a geared motion which drives the two brush yokes in opposite directions simultaneously. This may be changed to be operated by hand or be driven by a small pilot motor which in turn is controlled from a remote point.

Ratings

The machine is inherently a constant torque device so that it will have a rating such as 600/200 HP, 307/102 RPM and if required to deliver constant HP it will be oversize at the top speed.

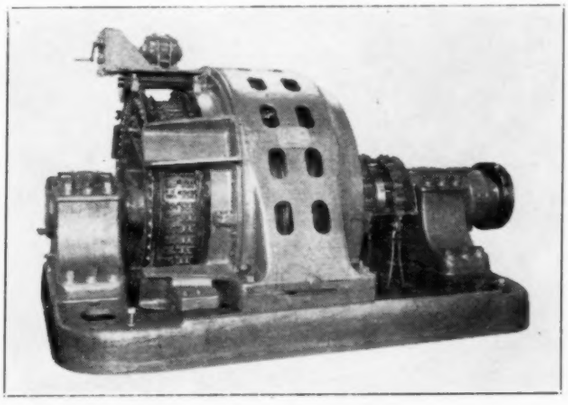


FIG. Q—Mill Type Brush Shifting Motor—Rated 600/418/200 HP. at 307/214/102 RPM. Note motor driven speed adjusting gear.

The slip energy only is handled by the commutator and regulating winding, so that such a winding capable of handling 50% of the motor rating at synchronous speed will allow adjustments of motor speed from 50% to 150% of synchronous. This is the usual range (3:1) for which the machines are built.

They have been built for some time in sizes up to 75 HP at the top speed, and two rated 600/300 HP 307/102 RPM, and 500/250 HP 130/65 RPM respectively have been in operation successfully on mill drives for several years.

Efficiency and Power Factor

The efficiency is slightly less than that of the standard machine because of losses in the regulating windings, but much better than that of a wound rotor machine using secondary resistance to obtain the same speed reduction.

The power factor is affected by the position of the brushes but is maintained at a high value 90 to 95% at the high speed; it is the same as that of a standard wound rotor machine at synchronous speed and falls to 65-70% at the minimum speed.

Summary of Characteristics, Advantages, and Disadvantages

This summary of characteristics is intended to include all features of construction and performance which are pertinent to operation and the most advantageous use, and necessarily includes both advantages and disadvantages as well as those qualities which may be of value in one application and a detriment in another.

1. The fact that the machine has an AC commutator and that AC commutation becomes relatively more difficult with increasing frequency limits its use in larger sizes to 25 cycle systems. The machine can be built for 60 cycle operation but is not competitive.

2. The most expensive part of an induction motor is the stator and the most expensive part of a DC motor is the armature and commutator. The stator and rotor of this machine are similar to those mentioned and consequently the cost of the motor is high.

Advantages

1. The motor has no auxiliaries of any kind and requires no direct current. In addition to the advantages inherent in the use of AC power there lies that of being dependent upon one power system only because if DC and AC are both used on one drive the failure of either will cause a shutdown.

2. The speed of the machine may be controlled by other regulating devices or instruments. For example to maintain a set air pressure in the case of a fan drive or by a device to make the speed of one stand of a mill keep a definite relation to that of another. This is easily done with DC machines but is not usually feasible with an AC drive.

3. The control is extremely simple and reliable.

Disadvantages

1. The machines include an AC commutator. All the methods of dynamic speed regulation include a commutator, some DC and some AC. Both are to be avoided if possible but of the two AC commutation is the more difficult and less desirable.

2. The fact that the full power of the motor is fed through slip rings at the line voltage limits this voltage to 440-550 volts and where the necessary power at this or lower voltage is not available requires transformers to provide it.

NOTES TO TABLE IV

There are proper fields of application for AC adjustable speed drives and other equally proper fields for DC drives and still others where the dividing line is very faint. It is very hard to make general statements about the use of AC or DC which are not misleading because so many different circumstances enter into the determination of the most suitable and most economical drive for a given purpose.

Therefore it seemed more logical and more practical to list these principal factors and give a brief statement of the influence of each upon the proper choice. This is done in the paragraphs following.

In addition it seemed possible to give tabular form to certain broad differences between AC and DC drives and to indicate the principal advantages and disadvantages possessed in common by the various types of each of the two methods. This has been done in Table IV.

TABLE IV—COMPARISON OF A.C. AND D.C. ADJUSTABLE SPEED MILL DRIVES

	ALTERNATING CURRENT (Kramer, Scherbius, Frequency Converter Drives)	DIRECT CURRENT (Field Control, Combination Voltage and Field Control, and Voltage Control Methods)
SPEED RANGE	2:1 is about the limit for economical construction; 3:1 obtainable in some types.	With field control 2:1 or slightly greater is standard construction while 3:1 may be obtained Combination field and voltage control allows range from 2 or 3 rpm up to maximum safe speed of machine which is 40 or 50:1.
SPEED REGULATION	2 to 5%.	With voltage control 2 to 5% with field control over 2:1 range one to two per cent. Less than 1% by use of regulating devices.
POWER SUPPLY REQUIRED	Mill A.C. distribution system—2200, 6600 volts, etc. 25 or 60 cycles.	For voltage control or combination field and voltage control —Separate M-G sets. For field control either M-G sets or converters.
CONTROL	Less simple than D.C.	Fairly simple.
EFFICIENCY	About 88-89% at extremes of range. Better nearer the main motor synchronous speed.	About 81-82% overall including losses in conversion.
POWER FACTOR	Sets have about 90-95% power factor.	Usually M-G sets have 80% leading power factor synchronous driving motor. Converters have unity power factor but are seldom used.
DISADVANTAGES	(1) Equipment not so familiar to operators and repairmen. (2) Speed regulation usually too large for tandem mills. (3) Speed cannot be subject to automatic control. (4) Not adapted to reversing drives.	(1) Relatively poor efficiency. (2) Requires A.C. to D.C. converting machinery.
ADVANTAGES	(1) Better efficiency. (2) Fed directly from plant distribution system without converting machinery.	(1) Machines and control are standard equipment with which operators and repairmen are familiar. (2) Speed regulation may be made small enough for tandem mills. (3) Speed may be subject to automatic regulation. (4) Adaptable to reversing mills.

FACTORS INFLUENCING A CHOICE OF A.C. OR D.C. FOR A GIVEN ADJUSTABLE SPEED DRIVE

Speed Regulation

For tandem mills where succesive stands are closely spaced so that the piece is in several at one time and the speed high it is usually necessary to have very close speed regulation on the order of one to two per cent to prevent pulling the piece in two and yet avoid excessive looping. This close regulation, at the present state of the art, can be obtained only with D.C. drives. Again in similar cases to that named and in rod mills where loops must be maintained between stands it is sometimes necessary to regulate the speed of a drive by that of another drive with an accuracy of a fraction of one per cent. This can only be done with D.C. drive.

Speed Range

The influence of the width of speed range on cost is given under that item. It is possible to obtain wider ranges on D.C. drives than with A.C. Thus while 2:1 ranges are practically standard for both and certain types of each may be built for 3:1 range beyond this figure it is usually advisable to go to D.C.

Efficiency

Where the tonnage of the mill is large the gain in power costs resulting from the higher efficiency of the A.C. drive will frequently be a substantial amount.

Power Factor

The A.C. adjustable speed drives will have an overall power factor of 90-95% which is about equal to and possibly slightly better than the usual plant power factor. Thus the power these drives take will not require any external corrective effect, but neither will it benefit that of the plant as a whole to any great extent.

D.C. drives supplied from synchronous converters will improve the plant power factor slightly but not largely, since they will take energy at unity power factor. When synchronous M-G sets are used for conversion these may easily be 80% power factor machines and thus furnish considerable corrective effect.

Service

Drives for reversing two high mills require quick reversals and rapid changes of speed under load and the operator must have full control of his drive at all points of the speed range. This flexibility can only be obtained with a special type of D.C. drive. Similarly some three high structural mills require a low entering speed for the first few passes and higher speeds for the others together with quick acceleration under load which characteristics can best be obtained with D.C. drive.

When it is believed that adjustable speed will later be necessary on a given drive, although it is not necessary now, it is feasible to install a constant speed A.C. induction motor drive and later add the necessary auxiliary equipment to obtain adjustable speed. This cannot well be done with a D.C. drive.

Cost

When it is once determined that either A.C. or D.C. will serve the purpose intended, then undoubtedly the most important factor is their comparative cost. This will be so influenced by the conditions of each application that it is impossible to give a figure for comparative cost which will apply to all drives. This can be reliably done only when all the conditions of power supply, number and size of drives, speed range, etc., are known, but it is possible to indicate how these various factors affect the comparative cost and to say that under a given set of conditions one or the other will generally be the cheaper.

Capacity of Drive

For drives under 500 HP D.C. is generally the cheaper because the cost per HP of auxiliaries for an A.C. set is high in small capacities. For very large drives 3000-4000 HP and higher the A.C. sets tend to become cheaper than D.C. because the cost per HP of the auxiliaries is then low.

Number of Drives

Where one drive only is concerned the A.C. set tends to be the cheaper but where a number of drives in the same location are involved and it is possible to use one or two M-G sets in common D.C. tends to be the cheaper.

Speed Range

A wide speed range, greater than 2:1 tends to make A.C. drive the more expensive while a range less than 2:1 tends to make it the cheaper.

Power Supply

Where it is possible to operate D.C. drives direct from the mill D.C. network without purchasing additional converting capacity then the D.C. drive will be far cheaper.

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*Developments in Steam Making**

By MARTIN FRISCH†

CENTRAL stations are seldom backward in exploiting developments which disclose possibilities of reducing the cost of making steam, which represents a major portion of the cost of making power. They have adopted most of the promising developments and improvements in boiler room equipment, especially fuel burning equipment, and these have led to cheaper steam and to cheaper power. It is regrettable that in spite of this some industrial engineers have the notion that to imitate the central stations is like trying to "keep up with the Joneses."

The same developments and the same opportunities for saving money in the manufacture of steam are available to industrial and steel mill boiler plants.

A Bit of Boiler Plant Economics

Experience indicates that the cheapest steam is not always made in the cheapest boiler plant, nor necessarily in the, thermally, most efficient one. A boiler plant needs to be, first, reliable and, second, economical. A given reliability has its price, irrespective of the efficiencies that can be built into the plant for that price. Higher efficiencies than these are justifiable if they pay their own way, and if they result in economies which yield a satisfactory return on the marginal investment needed to obtain the increased efficiencies.

To be reliable a boiler plant must have equipment that is mechanically correct, easy to operate and to maintain, and which is not sensitive to variations in the quality of the customary fuel.

To be most economical a boiler plant should be able to continuously turn out the maximum amount of steam per dollar when and as needed, which means that the sum of fixed costs, fuel cost and cost of operating and maintaining the steam plant must be a minimum for the steam produced by the plant during its useful life.

Plant Location Determines Best Combination of Equipment

It is unsafe to dogmatize as to what combination of boiler room equipment should be installed to

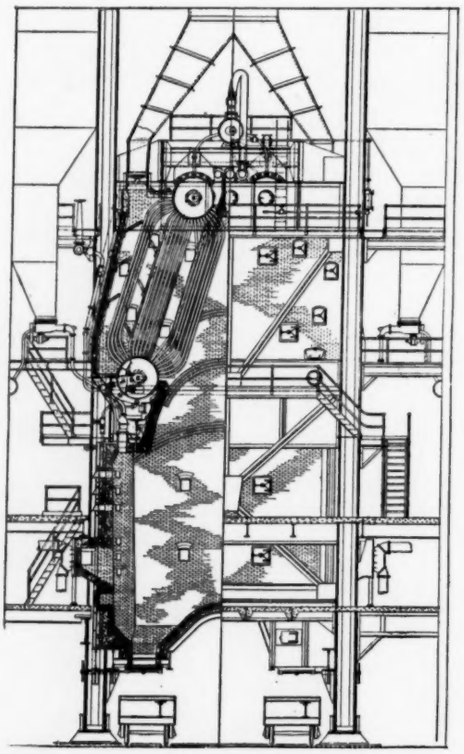

FIG. 1—No. 2 Unit, Fordson Plant. Before and after revamping to double steaming capacity of original boilers. Water walls in furnace represent only 12% of steaming surface.

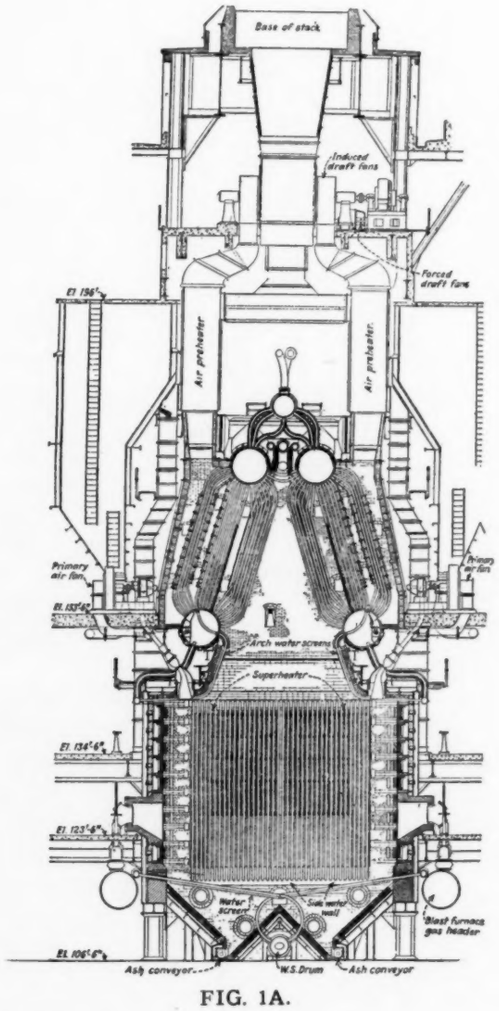

FIG. 1A.

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†Combustion Engineering Corporation, New York.

produce the cheapest steam. Much depends on the plant, for example: Its location, kind of load, and on the fuel and labor markets available. In general, the boiler plant which can burn with minimum trouble the largest variety of fuels, especially low grade coals and the boiler room which can be most readily and quickly adapted to other fuels such as oil or gas when market conditions warrant, will be the most economical for the "long pull," all other things being equal. This is especially true of steel mill boiler plants which generally have many unmarketable by-products or waste fuel available simultaneously. A plant's ability to burn wide varieties of fuel gives it bargaining power in the purchase of its fuel and renders it safe from disturbances in the supply of its customary fuel.

Pulverized Coal Fired Boiler Plants Have Unique Advantages

Pulverized coal fired boiler plants are unique in their built in ability to burn all grades of bituminous coals and in their built in ability or ready convertibility to burn gas or oil, when the market warrants. Furthermore, they are easy to operate and on account of the ease with which the proportions and completeness of mixing of air and fuel may be controlled and the rate of combustion varied, it is possible to maintain over long periods operating efficiencies which closely approach test efficiencies. This is true, also, because banking losses with this mode of firing are negligible. The "Serviceability" of such plants is high because boiler outages on account of the failure of the coal burning equipment are infrequent. This favors the attainment of high economic efficiencies from plants of conservative and unextravagant design. For certain load conditions and plant size the storage system of burning pulverized coal offers a means for firing boilers, which for reliability, flexibility, and economy is unexcelled. For other load conditions the unit system may prove more economical. Either of these systems may be so worked out that gas or oil may be burned alone or in combination with the pulverized coal with but minor modifications to the furnace.

The successful development of powdered coal firing for boilers has forced marked improvements in stokers and other furnace equipment and even in boilers.

Trend of Development

The general trend of the development work has been to increase capacities and efficiencies of given sizes of equipment and to reduce maintenance costs, and to eliminate or minimize difficulties of operation.

High Steam Capacities Now Customary

Steaming practice has changed. It is now commonplace and customary for boilers to be forced to deliver continuously many times their nominal rated capacity. Thus, in an industrial plant in Detroit, boilers, shown by Figure 1, whose rated capacity is 80,000 pounds of steam per hour, continuously deliver day in and day out 400,000 pounds of steam per hour per boiler and 500,000 pounds or more per hour when necessary to carry peak loads which may last for several hours. High rates of evaporation per square foot of boiler surface can be maintained continuously and economically. Generally, heat recovery apparatus which may or may not be cheaper than boiler surface is used to cool the gases leaving the boiler and to utilize the abstracted heat in the steam making process, say in heating feed water or in preheating air for combustion, if the savings warrant, as they most always do.

The indications are that very few future plants will be installed to operate at the low rates of evaporation customary only two years ago.

Powdered Coal Experience Emphasizes Latent Steaming Ability of Boilers

It was evident from the start that it would be possible to burn larger amounts of coal in powdered coal furnaces under boilers of limited cross sectional area than was then thought possible with stokers, whose fuel burning capacity was generally limited by the boiler width. This made powdered coal engineers soon realize that the amount of flue gas that can be put through a boiler, sets the real limit to the amount of steam that the boiler can make. They put boiler surface to work. Rates of evaporation of 20 to 30 pounds per hour per square foot of boiler heating surface are now being realized daily in industrial as well as utility plants under conditions most exacting as to realiability and economy. What is the significance of this? A given boiler can be counted on for more steam and fewer boilers and less boiler surface, and hence smaller boiler plants are needed to satisfy a given steam demand. A given investment for boilers results in lower first cost per developed boiler horsepower than was thought possible before. Money so saved is generally invested in efficiency increasing auxiliaries and in general such marginal investments yield handsome returns on account of the savings they produce.

Furnace Capacities Increase As Furnaces Improve

At first powdered coal combustion rates per cubic foot of furnace volume were lower than those customary in stoker furnaces. But this did not limit the aggregate fuel burning capacities of pulverized coal furnaces, because, by the simple expedient of increasing the depth of the furnace and the length of the flame and gas path through the furnace it was possible to increase the fuel burning capacity of the furnace beyond the limits usually thought attainable or practicable with the given boiler. Combustion rates up to 15,000 B.T.U. per cubic foot of combustion space were realized in solid refractory furnace burning 25,000 pounds or more coal per hour in the first large industrial boiler plant built to burn pulverized coal primarily. The development of air cooled hollow refractory walls and water screens extended the utility of powdered coal firing. These developments made combustion rates of 20,000 B.T.U. per cubic foot and furnace capacities of 35,000 to 40,000 pounds of coal per hour possible and these performances are still being maintained by the first plants to adopt them.

The obvious way to eliminate refractory maintenance is to eliminate the refractory from the furnace. So the next step was to put part of the boiler around the furnace by replacing refractories with water or steam cooled surfaces. This expedient eliminated the most serious limitation to higher combustion rates and higher capacities.

Water cooled surfaces proved satisfactory for the protection of stationary boiler furnace walls and

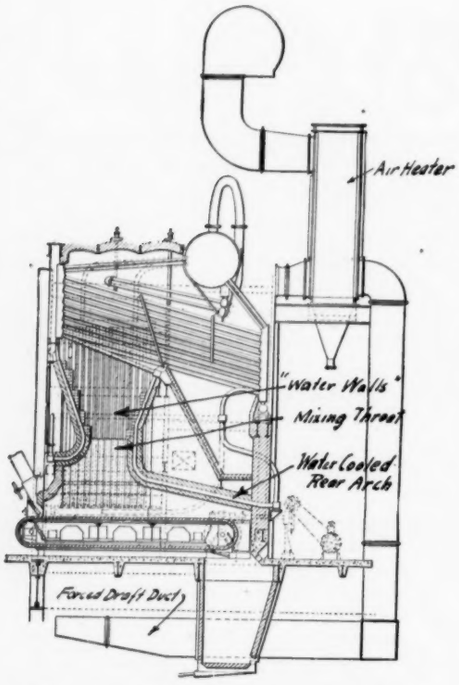


FIG. 2—Forced Draft Traveling Grate with rear arch for coke breeze and small anthracite. Furnace completely watercooled.

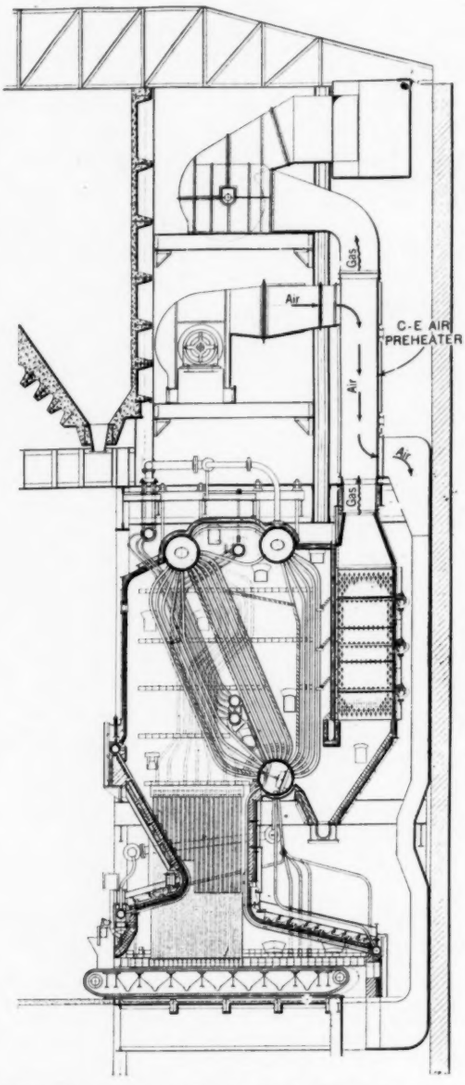


FIG. 2A—Forced Draft Chain Grate Stoker with rear arch. For lower grade bituminous. Furnace completely water cooled.

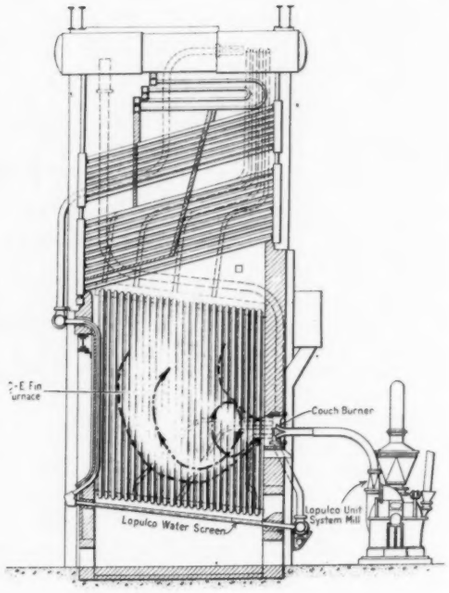


FIG. 3—Turbulence in horizontally fired furnace produced by large number of secondary air jets directed tangentially against an annular jet of fuel as indicated in Fig. 3A. The entire mixing is accomplished in the burner.

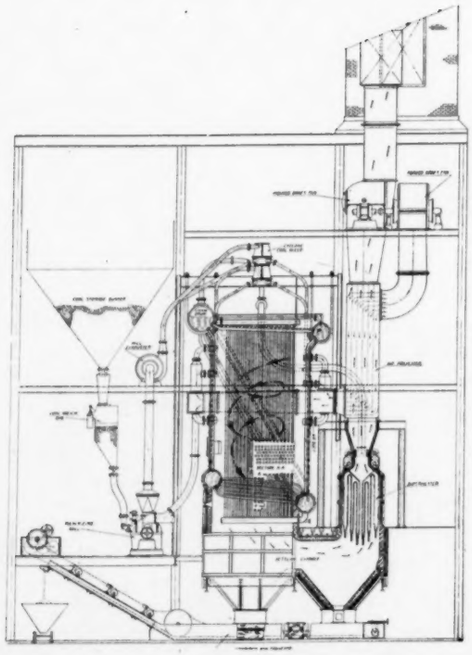


FIG. 4—Turbulence in tangentially fired furnace produced by directing fuel and air tangent to an imaginary circle in furnace as indicated in Fig. 4A.

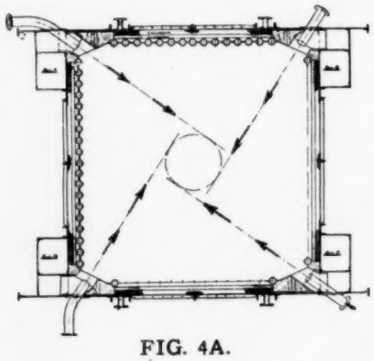


FIG. 4A.

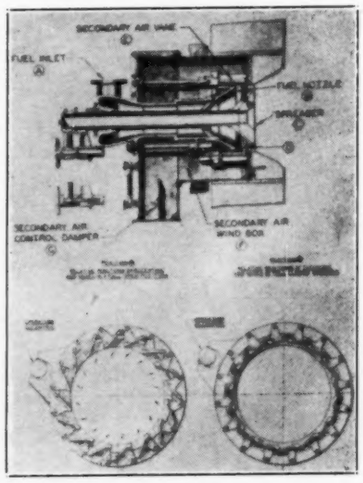


FIG. 3A.

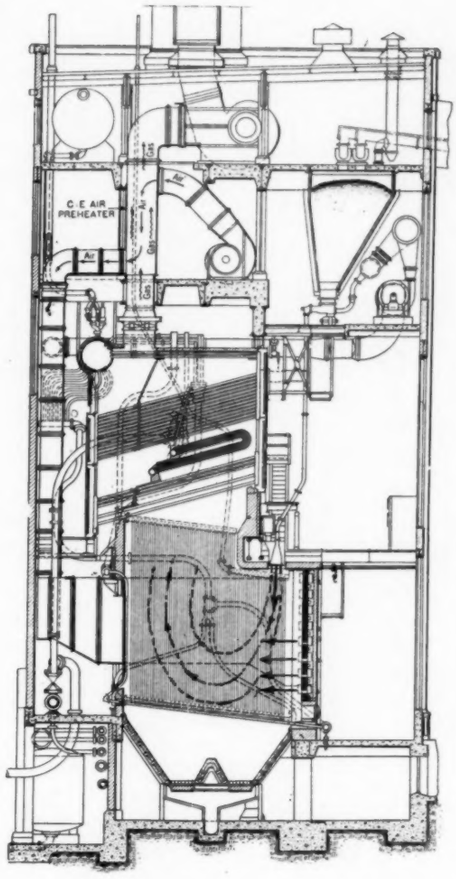


FIG. 5—Turbulence in vertically fired furnace produced by the impact of high velocity air jets against and at right angles to the burning fuel. Part of the mixing is accomplished in the burner shown below and part in the furnace.

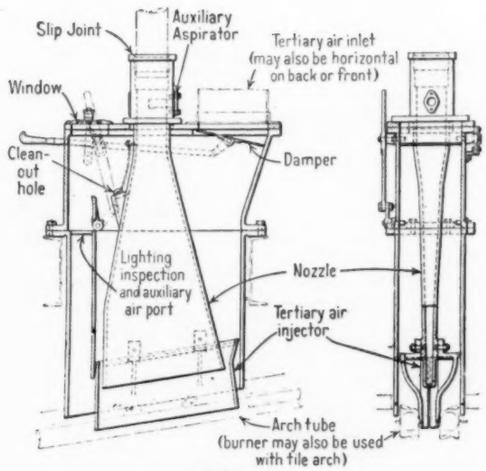


FIG. 5A.

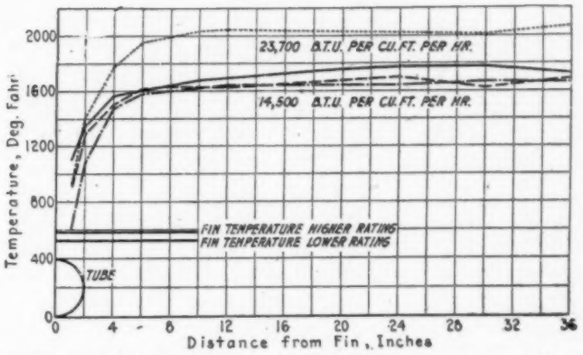

23,700 B.T.U. PER CU. FT. PER HR.
14,500 B.T.U. PER CU. FT. PER HR.
FIN TEMPERATURE HIGHER RATING
FIN TEMPERATURE LOWER RATING
TUBE
Temperature, Deg. Fahr.
Distance from Fin, Inches

FIG. 6—Variation of gas temperature from side-wall tube fins.

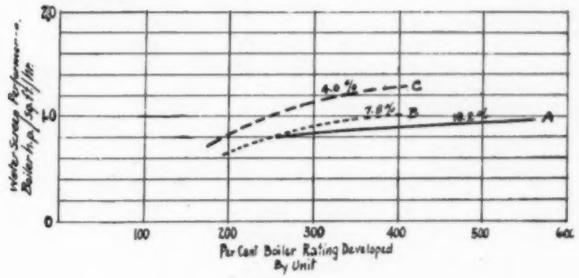


FIG. 7.

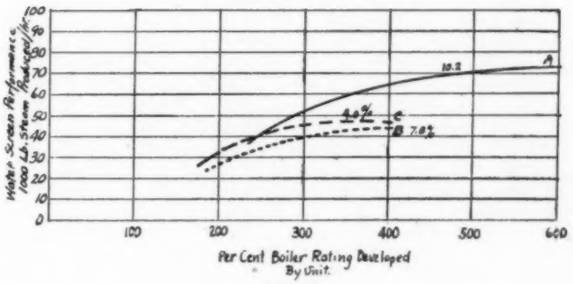


FIG. 8.

FIGURES 7 AND 8—Performance of typical water walls and screens. Key to Figs. 7 and 8.

A. Steel and auto plant.
B. Utility Plant.
C. Utility Plant.

Percentage figures on curves indicate ratio of screen to total steam generating surface.

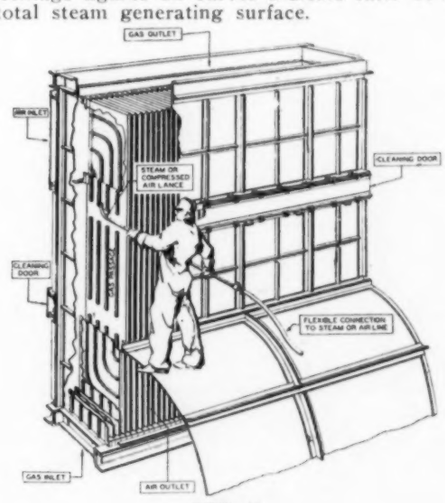
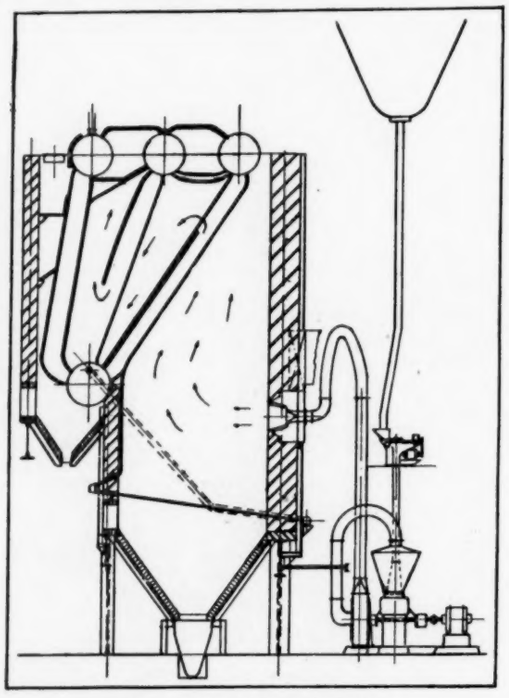


FIG. 9.

furnace maintenance ceased to be an obstacle to the application of highly turbulent modes of firing and the use of highly preheated air for combustion. Combustion rates of 30,000 B.T.U. per cubic foot and coal burning capacities of 60,000 pounds of pulverized coal per hour per furnace are now being realized in water cooled metal furnaces subject to turbulent firing with highly preheated air.

Stoker Improvements Accelerated By Pulverized Coal Competition

It was inevitable that the many advantages of coal dust firing should result in the widespread adoption of this mode of fuel burning by boiler plant engineers and managers. Stokers had to be improved to keep them competitive and stoker as well as stoker furnace improvements were not slow in materializing. That is as it should be, for the stoker still has its field. Forced Draft Travelling Grates are unique in their utility for the burning of coke breeze and small anthracite.



Cross Section Through Boiler

FIG. 10—Arrangement of steam generating equipment at Jones and Laughlin Plant.

Pulverized coal developments having blazed the way and set the pace, stoker furnaces are now being water cooled and stokers are no longer being set close to the boiler tubes, as in the past, but away from the boiler under large furnaces such as those employed in burning powdered coal. Stoker lengths and widths are increasing in order that high hourly coal burning rates and steam capacities may also be realized with stokers. The fuel burning capacities and efficiencies of underfeed stokers suitable for eastern high grade coking coals have been greatly improved by increasing greatly their lengths and by providing means for continuously removing ashes in such a manner that most of the carbon is well burned out of them before they are rejected into the ash pit. Clinker grinders under pit with considerable ash storage capacity are used for the larger applications. Large pits are used so that the ash may remain in them long enough to burn out completely before being ground out. Better means for air control are now also available and the use of high preheated air is now usual practice.

Attempts to produce turbulence in stoker furnaces, especially in furnaces fired with travelling or chain grate stokers have proved successful and this line of development has resulted in the rear arch and mixing throat. The utility of the rear arch is as yet imperfectly understood by most engineers but it is a very sound arch development. By means of it, low grade fuels high in moisture and ash and low in volatile may be burned without ignition difficulties. Most of the air is introduced into the furnace under the rear arch from the rear air compartments of the stoker, and if the rear arch is set close to the stoker, so that it may deflect the flames and burning gases toward and against the incoming fuel at the front of the stoker, it is possible to cause the immediate ignition of wet lignites, high ash and low volatile solid fuel such as coke breeze or fine anthracite otherwise hard to ignite without the use of heat reflecting or radiating arches. A properly designed rear arch stoker need not have the assistance of refractories in the furnace. The rear arch can be, and in fact should be completely water cooled. If a short front arch is used it could be water cooled as well. It has been demonstrated in several rear arch applications that radiant heat reflection from arches is of less consequence than usually supposed.

A modern application for the burning of coke breeze in a furnace entirely water cooled, even as to arches is shown in Figure 2. Anthracite fines and lignites are now being successfully burned in such furnaces.

Value of Water Walls and Air Heaters

The steaming capacity of a boiler can be increased by increasing the fuel burning capacity of the furnace. Generally, this necessitates that the furnace be water cooled in order to assure furnace reliability and that the gas leaving the boiler be passed through an economizer or an air heater in order to sacrifice no possible economies.

Water Walls Save the Cost of Refractory Maintenance and Make Steam

Metal water walls eliminate furnace maintenance and consequent boiler outage to a minimum. Metal water walls make it possible to squeeze the maximum possibilities out of fuel burning apparatus because there is no limit to the amount of mixing that may be produced in the furnace. There need be no fear from erosion or melting down of furnace walls. Nor need the amount of excess air used be governed by consideration of furnace maintenance for the furnace is safe from the effects of high temperature.

The furnace temperature is controlled only to keep the boiler from slagging and to keep the ash in the furnace in such a form that it may be readily rejected. With these necessary limitations, which vary in importance with the character of the coal, the kind of boiler, and on the ash removing means installed, higher temperatures and more efficient

combustion are being maintained today in completely water cooled furnaces than was ever possible in the best refractory furnaces. The reason is "Turbulence." The furnace designer can now go the limit in producing mixing burners and turbulent combustion, since he need have no fear of damaging the furnace by having too much commotion during the burning process, nor by using highly preheated air.

Turbulence may be produced by mixing burners, such as shown by Figure 3; or by the impingement of flames against each other at high velocity, as in tangentially fired furnaces, such as shown by Figure 4 or by causing air jets to impinge on the flames at right angles at high velocity as shown by Figure 5.

In stoker furnaces turbulence is caused by over fire air injection and by the use of the mixing throat and rear arch, as shown by Figure 2.

Some one in every meeting wants to know as to whether water walls cause smoke and in other respects interfere with combustion. It is only necessary in answer, to say that smokeless combustion is being obtained all over the world in completely water cooled furnaces at higher rates of combustion with lower excess air than was possible with refractory furnaces for the mixing process is being carried out so much better and the commotion or turbulence made so much greater in the water cooled metal furnace. Of course, the water cooled wall absorbs heat from the furnace, that's what protects the furnace walls. But as shown by Figure 6 summarizing results of tests made and described by the Bureau of Mines the cooling effect of the water walls extends but a few inches into the furnace and hence affects only the flame envelope. This indicates that even with imperfect turbulence, one should expect no more smoke from a well operated water cooled furnace than is otherwise usual.

Nor is it any more difficult, with properly designed fuel burning apparatus to maintain combustion in a water cooled furnace. It is impossible to put enough water cooling surface in a furnace to cause the fire to go out. It is surprising that some engineers should fear that such a thing will occur. Every furnace, not excepting a refractory furnace is a cold furnace every time it is started up. No one doubts that a cold furnace can be lighted and started up. Completely water cooled furnaces have been used for a hundred years. Locomotives, marine boilers, house heating boilers all have completely water cooled furnaces. I dare say most of these present have water cooled furnaces in their own basements.

Water cooled surfaces are installed primarily to eliminate furnace maintenance outages. But a derived "by-product" advantage of water cooled surfaces is their steam making capacity. A square foot of such surface will develop from ½ to 1½ B.H.P. It is evident that such surfaces will earn their keep, first, by the savings in furnace maintenance and outage and second, by the steam produced. Water cooled furnace linings are responsible for a considerable portion of the steam production of units so equipped as shown by Figures 7 and 8.

Air Heaters

Air heaters, such as shown by Figure 9, which have no moving parts and which are easy to clean offer a means of economically recovering heat that would otherwise be lost. In such air heaters alternating thin layers of gas and air divided by metal plates flow past each other at high velocity and counter-currently. The hot air returns heat to the furnace that would normally be lost to the atmosphere in the stack gases. Furthermore the preheated air accelerates combustion and brings about gains in efficiency and economy greater than those directly calculable. Preheated air may be used in conjunction with any method of fuel burning; stoker firing, oil burning, gas burning and pulverized coal firing. The economies to be derived will depend on the price of the fuel and the use factor of the plant.

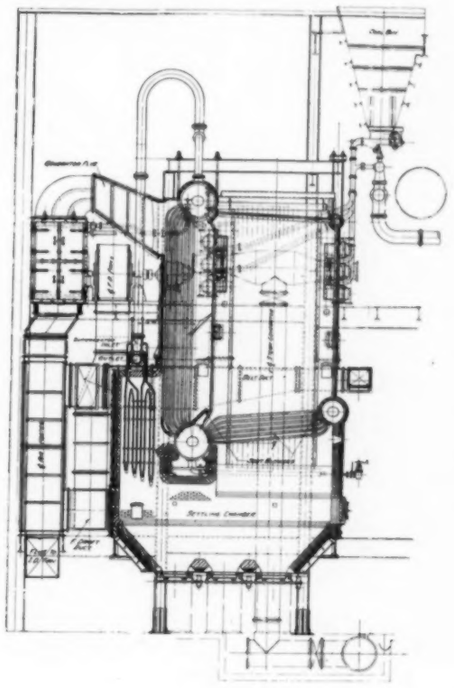


FIG. 11.

Steel mill engineers have been preheating air for use in blast furnaces longer than others, so that it may be superfluous to point out to them the advantages of a preheater, even for boiler firing. The preheater is a familiar tool to them.

Steel Mills Can Apply Developments to Advantage

Steel mill engineers need not feel that the developments described are of no interest to them just because steel mill boiler plants usually have so much waste fuel such as blast furnace gas, tar, coke oven gas and coke breeze to dispose of. If the supply of these waste fuels is so large, continuous and dependable that all the steam needed by the mill can be made thereby, that is one problem. But most steel mills have to make a great deal of steam with purchased fuel. Many of these steel mills have already followed the lead of the central stations and

have adopted the latest developments in steam making practice. As examples may be cited the Youngstown Sheet and Tube Company, the Jones and Laughlin Steel Company, the Colorado Fuel and Iron Company, the Tennessee Coal and Iron Company, the Ford Motor Company, and many others. All of those mentioned by name have adopted pulverized coal for some of their steam plants. Some of them burn pulverized coal, blast furnace gas, and even tar in the same furnaces. Others have modern travelling or forced draft chain grates for burning coke breeze. Water walls and air heaters are standard boiler room equipment in many steel mills. A great deal of the timidity at first displayed in the application of water cooling surfaces in place of

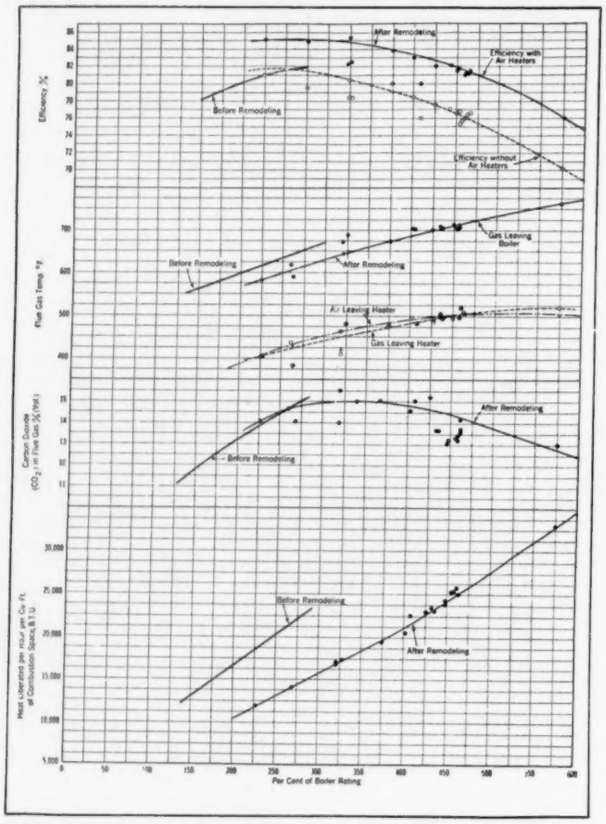


FIG. 12—Comparative performance of No. 2 Unit before and after remodeling.

furnace refractories is disappearing since steel mill engineers have found out in their own plants that cold and dirty blast furnace gas can be burned in completely water cooled furnaces. The same is true of coke breeze.

Figures 1, 10 and 11 show typical modern steel mill boiler plants. Of special interest are the steam generators, similar to the one shown by Figure 11, installed by the National Stamping Company and the Bethlehem Steel Company at Sparrows Point. In such an entirely water cooled furnace, blast furnace gas is being burned completely without difficulty at the Sparrows Point Plant.

Managers of other steel mills will discover in time that their boiler room is not just a dirty corner of the plant to be given as little attention as possible, but a place where money is being spent that should be saved. Many such boiler rooms can be remodelled and modernized so that the capacity of the installed boilers may perhaps be doubled by raising the boilers and by putting new furnaces under them and by installing suitable fuel burning equipment to serve them. The Ford Motor Company did that very thing at their Fordson Plant, which among other things manufactures pig iron and steel. A natural increase in demand for steam could not be met by extending the boiler plant for there was no room. Nor for the same reason could a new boiler plant be built. The demand was met by making the old boilers do twice as much work, by water cooling the furnaces, by installing air heaters and by doubling the capacity of the fuel burning equipment. Figure 1 shows the original and revamped units utilizing the original boilers. As shown by Figure 12 the capacities were doubled and the efficiencies greatly increased. What is more, the reliability of the equipment was in no way im-

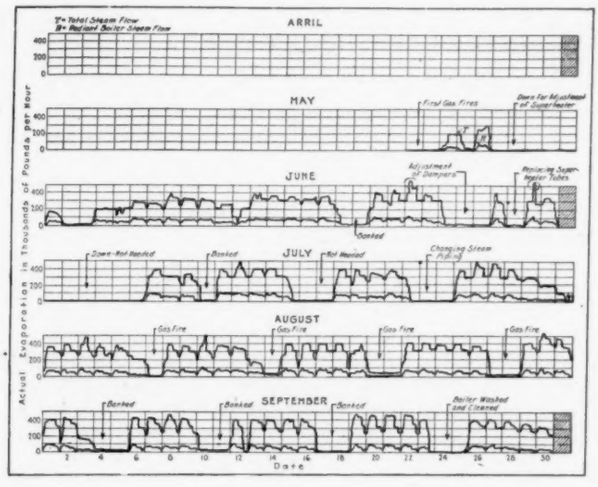
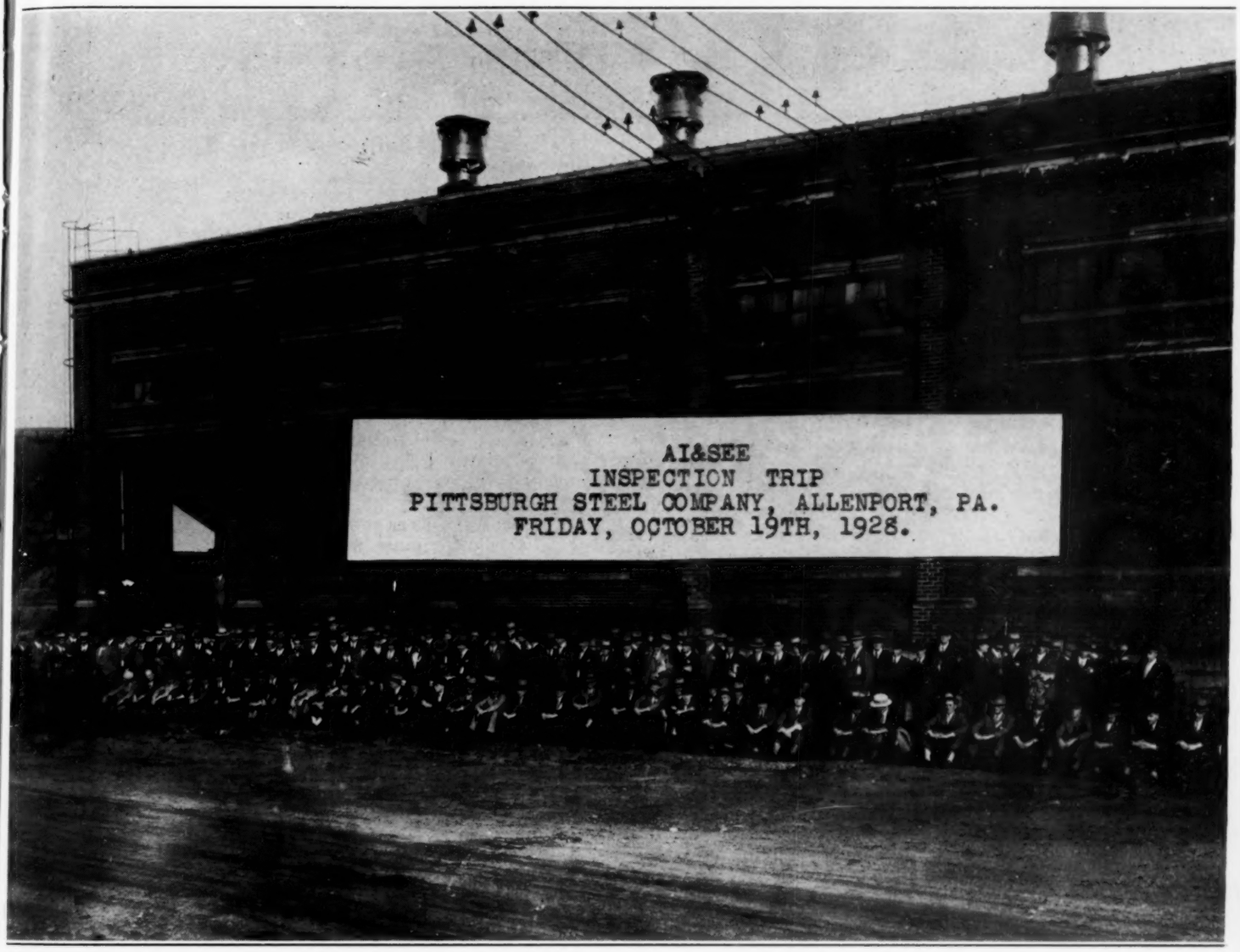


FIG. 13—Load and Service curves of Unit No. 4 of the Fordson Plant, since unit was put in service in May, 1927.

paired, in fact it was enhanced. As shown by Figure 13 high steam outputs were maintained continuously as required. These units are fired with pulverized coal and blast furnace gas. When available coke oven gas and tar burned in the same furnaces.

Conclusions

The capacities and efficiencies of steam generating units of usual dimensions have been extended, chiefly by improving furnaces, fuel burning equipment and by the utilization of heat recovery devices such as air heaters. Furnace reliability, capacity and efficiency has been improved by substituting for perishable refractory furnace linings, water and steam generating surfaces which can stand the intense turbulence and high temperatures produced by the improved fuel burning equipment now available. The requirements of powdered coal firing speeded up these furnace developments and encouraged parallel development of stoker, stoker furnaces and furnaces for the simultaneous utilization of several fuels such as oil, gas and pulverized coal. Central stations exploited these developments first and realized the economies disclosed by them. The same developments are available to steel mills and other industrial units making their own steam, many of them have already adopted them. The others are bound to follow suit.



About 200 members and guests visited the Pittsburgh Steel Company's plant at Allenport, Pa., on Friday afternoon, October 19th, 1928.

The principal feature of the trip was the Pilger Tube Mill using the Mannesmann Pilger Process. One of the important features in connection with this mill is its ability to pierce and form tubing directly from the cast ingot, thus eliminating the usual rolling processes between the ingot and piercing mill.

This mill is also able to roll extremely long lengths, having rolled an 8⅝" tube 131 feet long.

The entire mill is electrically driven with power supplied from the company's central power plant at Allenport.

The electrical equipment consists of 152 motors totaling 10,000 HP. The piercing mill is driven by a 2250 HP A.C. Motor. The Pilger Mills are driven by a 2200 HP D.C. Motor on the shaft of which is a sixty ton twenty-eight foot diameter fly-wheel.

There are eight electric overhead traveling cranes ranging in capacity from 7½ to 20 tons and in span from 63 to 118 feet.

Many of the auxiliary motors are wound rotor induction motors.

Another department visited was the small seamless tube plant where many ingenious methods for handling hot steel were noted.

This trip was one of the most interesting that the Association has engaged in for some time.

The arrangements were excellent for handling the crowd and the executives of the Pittsburgh Steel Company are to be congratulated for their painstaking efforts on behalf of the members of the AI&SEE.

A. I. & S. E. E. JUNIOR DIVISION

(Devoted to practical problems of electrical department employees in the Iron and Steel Industry)

Factory Testing of Electrical Apparatus

The information and data contained in this article was taken from the Westinghouse Electric & Manufacturing Company's Testing manual and if interpreted properly, will be of material assistance to the electrical maintenance department employees. This article will be continued in the December issue of the Iron & Steel Engineer.

DRYING OUT OF ELECTRIC APPARATUS

THIS operation, as conducted in the factory, is practically limited to the proper preparation of insulation previous to its impregnation with oil or gum and is carried out in suitable ovens or steam heated tanks. However, if an excessive amount of moisture is found to be present in the completed apparatus, it is returned to the assembling section and again subjected to the same drying out process as before. Facilities have been provided in certain cases for determining the insulation resistance of apparatus while still under vacuum so that its exact condition relative to moisture may be readily obtained at any time, thereby removing any uncertainty as to the length of time required to complete the process.

In the field, the drying out of apparatus is not so simple a matter, as suitable facilities are rare. It is frequently, however, a very essential operation before a machine may be placed in service, as, due to the varied conditions to which it has been subjected during shipment and installation, sufficient moisture will often have been absorbed to render a breakdown liable unless such precautions are taken.

The drying out of the insulation of completed apparatus consists in driving out the moisture present by means of heat applied in such a manner that the insulation itself is not damaged during the process. It is essential that the heat be brought up gradually at first; the aim being to allow the water vapor to find its way out through the natural pores in the material much in the same manner as it came in. Too rapid heating is liable to develop such pressure in local portions that new passages are forced through the insulation, thus injuring it permanently. Fifteen to twenty hours should be consumed in bringing the temperature up to the value required. This value depends, to some extent, on the method of heating and temperature measurement, but a maximum temperature of 80°C. as measured on the external portions of the insulation is considered good practice. This temperature should be as uniform as possible throughout the machine, so that moisture driven from one portion will not condense on another. Sufficient thermometers must be used to insure that no portion reaches an excessive temperature. After the temperature has risen to the maximum value specified, it must be held practically constant until the insulation resistance reaches the desired value. Measurements of insulation resistance must be taken at regular intervals and the values obtained plotted in the form of a curve. The drying out process should be continued until the curve flattens out.

The heat required in the above process may be supplied from an external source or may be generated internally or in certain cases both these sources of heat may be utilized at the same time. The method to be preferred in any case depends to a great extent upon the local conditions, but the one combining both external and internal heating, when applicable, gives quicker and better results.

When heat is to be supplied from an external source, the machine should be enclosed in a wooden box with holes in the top and near the bottom to allow proper air circulation. The clearance between the machine and the box should be as small as practical, so that most of the heated air will pass through the ventilating spaces in the machine. Suitable grids, through which either direct or alternating-current may be circulated, are placed in the bottom of the box to supply the heat required. Care must be taken in applying heat in this manner that the machine is protected against direct radiation from the heater; also that no inflammable material is close to it. It is advisable, in such cases, to line the lower part of the box with asbestos. Instead of placing the heating element inside the box with the machine, it may be placed outside and the heat carried into the bottom of the box through a suitable pipe. When this plan is followed, the heat may be generated by direct combustion of gas, coal or wood, provided that none of the products of combustion be allowed to enter the box containing the machine. This method is to be recommended only when electric power is not available.

When the heat required is developed internally, current is circulated through the winding of the machine itself, either from an outside source or generated under short circuit conditions. The latter method is the one usually followed. In the case of transformers, the required current may readily be obtained by short circuiting one winding and impressing a suitable voltage on the other. The total winding must be used in each case; otherwise, the various portions of the insulation will not be treated

uniformly. The current required will vary, but approximately one-fifth the normal value will result in a temperature of 80°C. as desired. To obtain this current, a voltage of approximately ½ to 1½ per cent of normal will be sufficient. If an adjustable voltage of approximately the value desired is not available, suitable resistance may be used in series with the winding excited to control the current. During this process, the oil should be removed from the transformer case and its cover left open so as to allow some circulation of air around the windings.

In the application of the internal heating method to rotating machines of the open or semi-closed types, the armature winding should be short circuited, provisions being made in the wiring for measuring the current flowing at any time. The machine is driven at a low speed and the field current adjusted to give the armature current desired. This should be about one-tenth normal to start, being gradually increased until a temperature of 80°C. may be maintained constant. Care must be taken, however, that the current used is not excessive. The fact must be kept in mind that the temperature of the insulation in the internal parts of the machine next to the copper itself may be at a temperature widely different from that measured on the external portions. With this in view, the current flowing should never exceed 125% of normal unless special information otherwise is given by the Engineering Department.

In cases where it is not possible to obtain a temperature of 80°C. on the external portions with safe values of current flowing, an effort should be made to restrict the natural ventilation of the machine as much as possible. Blowers, if present, should be removed and the machine covered with building paper or a tarpaulin in order to retain the heat.

In enclosed machines, such as turbo generators, the air circulation should be modified so that the outgoing air will pass directly to the intake; in this manner, the heating effect will be cumulative, the leakage usually being sufficient to carry off the moisture. In some high speed enclosed machines, the air friction alone, if the inlet and outlet are closed, is sufficient to raise the temperature to the value desired. In such cases, the field should be so excited that about one-third normal current will flow in the short circuited armature windings to insure that the inner layers of the insulation are several degrees hotter than the outer.

On account of the comparatively low value of the total heat units available, when this method of depending entirely on the copper losses in the machine to supply the heat required in the drying out process is followed, it becomes a long drawn out procedure. When it is practical to supplement this course of heat by supplying additional heat from an external source, the time required for the process will be materially reduced and, on account of the greater uniformity of the temperature throughout the insulation obtainable with this combination method, the final results will be better.

However, even under these conditions, this process may consume from one to three weeks or longer, depending on the conditions existing and the nature of the apparatus. The best plan is to obviate the necessity for such procedure whenever possible by the suitable protection of electric machinery from the time of shipment until placed in active service.

PERFORMANCE OF MACHINES

The performance of electric apparatus depends on three factors—the design, the nature of the material and the quality of the workmanship. To reproduce the same performance, each of these factors must be duplicated. However, owing to variations in materials and limitations in the accuracy of machining operations, exact duplication is seldom obtained. It is, therefore, customary to express the performance of apparatus in certain respects as approximate.

In view of the conditions stated, the following variations from performance values which may be specified are considered reasonable.

In computing the efficiency of rotating apparatus, a variation in the total losses equal to 10% of the losses at rated load, as computed from the specified efficiency, may be allowed at each load.

In computing the regulation of alternating-current generators, a variation in the short circuit ampere turns may be allowed at each load equal to 10% of that value at rated load, as computed from the specific regulation.

In determining the power factor of induction motors, a maximum variation may be allowed in the inductive component of the current at each load to 10% of the inductive component of the current at rated load, as computed from the specified power factor.

A variation in speed of motors from that specified may be permitted, as stated below, the percentage being based on the value specified for rated load.

Railway Motors cold — 2 + 6%; hot ± 4%

Other D-C. Motors under 10 Hp. ± 7½%

D-C. Motors 10 Hp. and over ± 5%

Determination of Performance

The performance of a machine is determined when its characteristics, in the following respects, have been established.

(1) Mechanical operation.
(2) Electrical operation.
(3) Economy of operation.
(4) Heating characteristics.
(5) Effectiveness of the insulation.

No attempt will be made, however, to classify the various testing operations under these heads, as many of the tests relate to more than one of them. The various operations will be taken up in their logical sequence, as far as possible. The actual test floor procedure varies, depending upon which test may be conducted most advantageously under the conditions existing at that time.

It is to be noted, however, that whenever complete performance tests are available on a given design only Standard Commercial tests will be made on subsequent units built to the same or essentially the same design.

MECHANICAL OPERATION

Preliminary Inspection

Before the machine is assembled, the diameter of the rotating part and the bore of the stationary

part must be accurately determined. This measurement is made by a competent member of the Inspection Department and recorded, together with the corresponding data, as specified in the manufacturing information, on the back of the inspection tag accompanying the machine. This information must be transcribed by the tester to the test sheet of the machine.

The field poles must be checked carefully to determine if they are correctly spaced and parallel to the axis of the machine. The assembly of the commutating poles is checked independently of the main poles also in reference to them as it is essential that they be correct in both respects to insure satisfactory electrical operation.

After the machine is finally assembled, the clearance between the revolving and stationary parts must be carefully measured by feeler gauges to determine whether the revolving part is central and parallel to the axis of the stationary part. The location of the brush arms relative to the poles, the grade of the brushes, the angle of the brush holder with the commutator and the bringing out of the leads must all be checked to insure that they correspond with the manufacturing information. When checking the wiring around the frame, the connections to the field coils and armature must be compared with the drawing to see that the various terminals are in their proper positions on the terminal blocks. It must also be noted that there is reasonable spacing between terminals of opposite polarity on the same block and that no terminal or connection to its approaches sufficiently close to the frame of the machine to render grounds possible.

SETTING UP MACHINES

In determining the place where the large machines may be set up for test, it is necessary to consider all the surrounding objects, such as resistance racks, ventilating pipes, doors, walls or any other feature that will, in any way, influence the air circulation or affect the temperature. The accessibility of the required testing facilities must also be kept in mind. In no case must a machine be set up until its proposed location is approved by the foreman of the testing section. Machines must be set up level and securely fastened.

After a machine is ready to run, the bearings must be filled to the proper level with oil. This is always slightly below the overflow as the oil rings will churn the oil and raise the level when the machine is running. In the case of very large machines with heavy revolving parts, it is well to thoroughly flood the bearings before attempting to start the first time. Special care should be taken not to overflow the bearings or to spill oil on the outside, as it makes an untidy appearance and also makes it impossible to detect small sand holes, leaks, defects in the bearing housing or oil throwing.

BELTS AND PULLEYS

For load test, especially when the two units are belted together, special precautions must be taken that the machines are lined up properly. Pulleys should be selected to give a belt speed of from 3500 to 5000 feet per minute and carefully inspected for defects. Belts must be selected with care; 100 lbs. pull per inch of width is considered the maximum overload limit for a double ply belt in good condition and this value should not be exceeded except when particularly instructed by the person in charge. A convenient approximate formula for computing belt pull in any case is, as follows:

$$\text{Pull in lbs.} = \frac{\text{Horse Power} \times 33000}{\text{Speed of belt in ft. per min.}}$$

Curves computed on this basis are given in Fig. 1. Belts should be put on so that the pull is on the lower side and they should be run with the inner lap, not against it. Belts must not be wider than the pulley.

Any tendency of the rotors of machines mounted in temporary shop bearing, such as engine type machines, to pull over under heavy load must be caught as early as possible to avoid possible injury to the

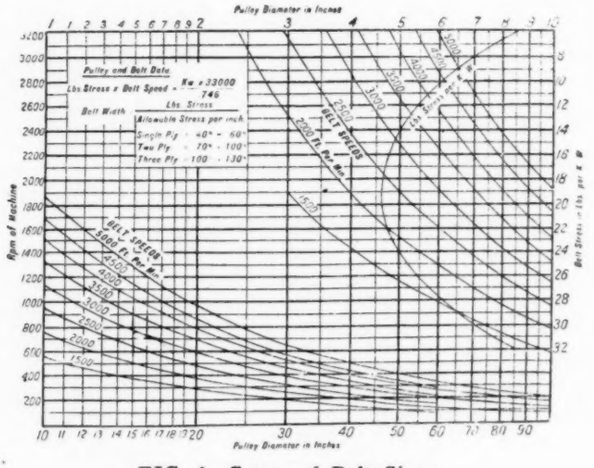


FIG. 1—Curve of Belt Sizes.

machine. Oil rings must be inspected from time to time to insure that the oil is being carried up properly. The temperature of the bearings should also be observed.

POLARITY TESTS

While the inspection of the wiring around frame, as stated before, will, in most cases, insure that the polarity of the fields is correct, the incorrect assembly or winding of the coils may give rise to incorrect polarity even though the connections are correct. For this reason, the actual relative polarity of the poles must also be determined electrically before other tests are taken. The result obtained must be noted on the test sheet.

The most convenient method of determining polarity is with a compass or a small piece of steel wire. The compass is passed slowly around the poles; if the polarity is correct, the needle will reverse its position as it is moved from one pole to the next. If the fields have once been excited, the residual magnetism will probably be strong enough to show their polarity, but it is better to excite the coils with a very weak current. If the current is too strong, it may change the polarity of the compass and, therefore, give unreliable results. The power circuit must be connected to the various field circuits in such a manner that the current will have the proper direction in each in order to determine the relative polarity of these field circuits.

If a compound machine is connected in the cir-

cuit and it is not convenient to check the relative polarity of the shunt and series coils in the manner described above, the correctness of the field connections may be determined by running the machine first as a compound motor, and then as a series motor, and noting the direction of rotation. If the machine is a generator or a differentially compounded motor, the rotation should be in opposite directions, while for a motor of standard compounding, the direction of rotation should be the same under each condition. Care must be taken when running the machine under series excitation only, that an excessive speed is not attained. It is only necessary to note the direction of rotation and not essential that normal speed be attained, in either case.

When the machine is a generator, it is often more convenient to determine the polarity of the series field winding by short circuiting each series coil in succession, while operating the machine under rack load and noting the effect on the terminal voltage. The voltage should decrease as each coil is cut out.

The relative polarity of the commutating poles to the main poles must be as follows: For generator, the commutating pole must be of the same polarity as the main pole ahead of it in the direction of rotation, while for motors, the commutating pole must be of the opposite polarity from the main pole ahead of it in the direction of rotation. When only two commutating poles are used, on a four pole machine, these are of the same polarity and bear the above described relation to the main poles.

STARTING MACHINES

Machines should be started slowly and brought up to speed gradually, observing in the meantime, that all oil rings are operating freely and carrying oil and that no parts are rubbing. The balance and end play must be particularly observed. Excessive vibration may be due to the rotor not being properly balanced, bent shaft, poor alignment, or unbalanced magnetic condition. Other features, such as eccentricity of the spider rim, unevenness in windings or in the banding and proper clearance of all revolving parts must be noted. Any defect found in the machine must be reported to the foreman before proceeding with the test.

Mr. A. G. Place, Died Thursday, October 25, 1928

It is with a feeling of great personal and official loss that the Association of Iron & Steel Electrical Engineers advises its membership of the death of a highly esteemed Association Executive.

Mr. Place was a valuable active member of the A. I. & S. E. E., serving in various capacities for the past fifteen years. He served the Association as Director, Secretary and 2nd Vice President. His contributions to the Electrical Art in the United States were many, and his opinions and experiences were respected by the electrical authorities in this country.

Mr. Place was born at Woburn, Mass., September 27th, 1887. He was educated at the Massachusetts Institute of Technology, graduating as an Electrical Engineer in the class of 1908. His first connection was with the Northwestern Power Company at Seattle, Wash., and from that company he came to the Youngstown Sheet and Tube Company as an Electrical Engineer in 1913. His abilities soon obtained him recognition and he was rapidly advanced to the head of his department.

Mr. Place supervised the installation of many of the modern rolling mill drives that are now operating at the Youngstown Sheet and Tube Company.

Items of Interest

DIRECT CURRENT METAL ARC WELDING

In a paper delivered before the American Institute of Steel Construction at Biloxi, Mississippi November 14, by Fred T. Llewellyn, President, American Welding Society, two questions of interest were answered by the author.

***Is there some way of determining the reliability of the completed weld?**

This is doubtless the most important question to be answered. All the foregoing features are secondary as compared with the question of reliability. Whether a structure be designed with unit stresses of 2,000, 2,500 or 3,000 pounds, per linear inch of fillet weld, is of little consequence unless the weld is good. On every hand one is asked, "How can we be sure whether a weld is sound? Can we eliminate the human equation?" These are natural and proper questions, and nothing is to be gained by side-stepping them.

There have been developed a number of methods for investigating reliability in welding, such as visual inspection for shape and color, flame test, X-ray examination, and the electric conductivity test for potention-drop. Automatic processes are also finding increased fields of application. All these things are good (visual inspection is especially feasible and significant), but from a rigorous standpoint the writer believes that we can no more be certain that a specific portion of weld is sound, without destroying it, than we can tell whether a specific rivet fills the hole, without destroying it. Expressed conversely, it is just as possible to determine the reliability of a completed weld as it is possible to determine the reliability of a riveted joint.

We have confidence in rivets, and rightly so, not because the inspector's hammer rings true when applied to their heads (it is well known that a poorly driven rivet can be given a resonant head), but because we have used them with satisfactory results over a long period. Confidence in rivets has been a thing of growth. Thirty-five years ago all structural specifications limited field rivets to only two-thirds the value allowed for shop rivets. Today that classification has gone, and the distinction is between hand-driven and machine-driven rivets. We have acquired confidence in the machine-driven rivet.

If welding is to be considered seriously as a structural tool similar confidence in its results must be given opportunity to develop. This may be done in several ways:—

(1) By familiarity. Let every structural shop do some welding, no matter by what process. If there be any hesitancy regarding major points then weld the minor ones, but install at least one equipment and use that as a nucelus. Let us become "welding minded!"

(2) By flame-cutting cut short sections of weld and examining their interior. They can readily be replaced by the process of welding without detriment to the joint.

(3) By occasional non-descructive tests on portions of a completed structure, with loads of, say, one and a half times those for which it was designed.

(4) Most important of all, by qualification of the welder. This is very necessary, and fortunately it is both feasible and significant. The Structural Steel Welding Committee has prepared a specification for qualifying welders (Section B) whose requirements cover what may reasonably be expected in commercial practice. Printed copies are being distributed among the shops participating in the preparation of specimens. Pending the completion of the committee's final report this document may be considered as a tentative standard that represents our best knowledge today. The results of these qualifying tests should be significant of a welder's subsequent work, for such has been the experience in many shops where similar tests have been applied. Welders, as a class, are conscientious and take pride in their product.

(5) By a proper selection of welding wire. The importance of this feature has already been emphasized in Answer One.

Can the welding operations be done at a competitive cost?

To this question the writer would give a qualified answer: For certain classes of work, "yes!" For other classes of work costs so far available have been higher than for older methods of fabrication and assembly. The higher costs appear to be reflected, not so much in the expense of making the welds themselves, as in the labor involved in preparation. In certain kinds of work this labor resulted from the need of cutting rolled steel members to closer length tolerances than are the established practice at the mills. In all cases where material had to pass through a shop, costs were augmented by the fact that so far there has not been sufficient volume of structural welding to keep a given shop continuously busy.

With fabricating shops organized along existing lines in which welded jobs are undertaken only occasionally, the following classification of work from an economic standpoint seems to represent our experience:—

(1) Competitive costs can be secured on **low beam-and-column buildings** whose details are sufficiently simple to permit the rolled steel members to be shipped unfabricated from the mill direct to the site, thereby requiring only field welding.

(2) Competitive costs can be secured an certain types of shop-welded structures in which considerable savings in weight are securable, notably in **truss-work** wherein the net section of tension members is a criterion, and where gusset plates and

other expensive details can be largely eliminated.

(3) Competitive costs are frequently securable on existing bridges and other structures which require **reinforcement** to meet added loadings. The saving here is largely due to the avoidance of the expensive hand-drilling of holes in the field.

(4) Competitive costs may **not** be securable on the **taller beam-and-volumn buildings**, whose details are so important as to require shop preparation, **until** such time as there is **enough business** of this character to occupy a shop continuously.

(5) There is a class of tall beam-and-column buildings which, from a broader economic standpoint, can be welded with advantage, regardless of present costs for such work. This class embraces **additions** to buildings already occupied, where the elimination of noise during construction has real monetary value. Hotel owners are becoming alive to this feature, and it is also a factor in some other commercial buildings as well as in the case of hospitals and colleges.. The saving of space during alterations, and the smaller amount of demolition made possible by welding, also make this process economical as applied to the detailed connections of a new to an existing structure.

FURNACE DOOR OPERATION

It is often the most obvious things in our daily life that escapes our notice . We go on doing the same things over and over without ever giving a thought to whether it is possible to do them a better way.

One of the most obvious and yet least noticed mechanisms in the plant is the hydraulic door hoist system. It is unnoticed until something goes wrong with it and then it becomes very obtrusive (and expensive).

If the night gang happens to miss a leaky cylinder and the water drips down on a furnace roof, you are soon reminded that you have the hydraulic system!—(though you no longer have the furnace roof).

Manipulating valves, under the high pressure used, do not stay tight very long, and when they start to leak the openings enlarge very rapidly. So most pumps are called upon to handle a lot more water than is ever used. And it costs money to maintain high water pressure in a leaky system.

Once one starts to think about it, he soon realizes how fine it would be to get the bulky manifolds off the charging floor, to take the water cylinders from above the furnaces, to never have to worry about frozen piping and to have furnace doors that don't creep open or shut, but "stay put."

It is pretty well agreed among steel men that the most satisfactory way to move furnace doors or in fact to move most anything about the plant, is by electric motors. There are several ways to do this, one way being to arrange an individual motor and hoist to take care of each other, but this is the expensive way. It requires as many motors and hoists as there are doors. The better way is to use a single motor to operate all the doors of a furnace, in connection with a selective hoist mechanism to enable the single motor to operate any door at will.

One steel plant with fourteen five-door furnaces thus operates all of its doors by the use of fourteen motors instead of seventy. The cost of motors and maintenance items on the 14 motors and hoisting mechanisms are practically negligible compared with the purchase, maintenance and operation of 70 individual motors and hoists.

ARC WELDED STRUCTURAL BUILDING

Steelwork is in progress on the Chalfonte-Haddon Hall power house job, but the neighbors are undisturbed.

A new process, as applied to the building industry, electric welding, is being used. And while the building progresses swiftly, it progresses silently.

The electric torch is the mark of a new era in assembling steel beams into the framework of a building. Until lately people who had been living in peace and comfort near the site of a building found peace and quiet impossible during many weary weeks when the ironworkers got on the job, and sometimes all night, and those who couldn't take a trip abroad while the structure was being shaped either went slightly mad or invented new cuss words.

Now that is all changed. As building work goes, building steel framework is presently a mannerly and modest phase of the activity. The beam is carried into place and then a workman approaches carrying an instrument that slightly resembles an oil can, only instead of a spout there is a long thin wire for the electric spark. He wears a steel mask when the juice is turned on, for the light it throws in the face is terrific. He seals the beams together without pounding, without any excitement whatever, and goes on to the next.

Although the welding process has been much used in such work as the fabrication of girders and castings, it has only recently been adapted to the building industry. The process on buildings in the recent past has been so successful, however, that it is believed it will revolutionize the construction of steel framework.

Incidently, the local powerhouse job will be the highest and most substantial building ever welded. and engineers and steel contractors in all parts of the country are watching the progress of the resort project with interest. The addition now under way is an eight-story building, 134 feet in height, 80 feet wide, and 74 feet deep, the steel framework of which is to be entirely welded together.

Engineers on the job say the welding process has many advantages. It not only eliminates the noisy rat-tat-tat of the riveter, always a source of disturbance to the surrounding district, but is said to be cheaper, quicker and more reliable.

Leroy Shaw, welding inspector here for the General Electric Company, said that one man operating an electric welding outfit can do the work of four men using the riveting-gun method. On the local

job, he said, it would take only four weeks to complete the steel erection by the welding process, whereas, if riveting was specified, it would probably take several weeks longer.

Fewer tools are required and no rivets are used in the welding process, both items representing another saving, he added.

The only tool used in the process is a General Electric welding machine having a capacity of 460 volts and 400 amperes, an oblonged-shaped instrument with an electrode at one end. A wire three-sixteenths of an inch in diameter and composed of 98 per cent steel is used as the connecting material in place of rivets. In most cases, the wire is 12 inches in length, although any amount may be used in the fusing together of a connection.

Before actually welding together two girders, they are first bolted together in order, to fix them in a secure and accurate position. This is done usually by means of angle iron supports and clamping plates.

With the girders in position, the workman places the wire between the two and applies the electric welder to the wire. The electrode on coming in contact with the wire and girders causes an arc of 200 amperes which melts the wire and fuses the two girders together. Steel is fused with steel and becomes a solid mass which hardens almost instantly after which the bolts and angle irons are removed.

Mr. Shaw stated that previous and careful tests had shown that welded girders will stand up better than those riveted together.

The same tests, he stated, also showed that the welded section was even stronger than any other part of the girder.

The welding on the power house job is being done by workmen of the Bethlehem Steel Company. The welders are compelled to wear headshields with brown-colored glass in order to protect their eyes from the intense glare caused when the 200-ampere arc is formed.

Katchan and McQuade of Philadelphia, are the general contractors for the job which will cost about $250,000. When completed the Chalfonte-Haddon Hall power house will cover a plot, 74 feet by 142 feet, and will be the largest privately owned power plant in this section of the country.

YOUNGSTOWN SHEET AND TUBE COMPANY BUYS ELECTRICAL EQUIPMENT

The Youngstown Sheet and Tube Company has just recently placed a quarter-million dollar order for electrical equipment for a 44-inch electrically driven reversing blooming mill with the Westinghouse Electric and Manufacturing Company.

This new equipment, which is to replace an existing steam engine drive that has been in operation for fourteen years, will be installed in the Campbell Works in about five months.

The mill will be driven by a 7000 HP. single unit direct current reversing motor operated at 50-120 revolutions per minute. Power for the motor will be supplied by a flywheel motor generator set consisting of two 3000 kilowatt 700 volt generators operating at 360 r.p.m.—one 5000 HP. 6600 volt, three phase, 60 cycle A.C. motor—and a 140,000 pound steel plate flywheel.

The equipment will be under the control of an operator located in the mill pulpit. A feature of the control is a foot operated master switch, which completely controls the reversing motor and allows the operator to take care of some of the auxiliary operations with his hands. It is expected that substantial savings in operating costs will be realized with this equipment over the present steam engine driven mill.

THE MAN IN THE MILL

By PATRICK SHEA*

THE works of the Ancients fill many a tomb,
(Men who their own worlds did sway)
The pages of Greece, the annals of Rome,
And Babylon's tablets of clay;
Survey all their wonders, and praise them who will,
They're surpassed in this day by the man in the mill.

His achievements are wonderful, useful, sublime,
Unlike the great builders of old,
Not to outlast, to save hurrying time,
And marvelous them to behold;
Yet, no proud pillared temple, no shaft on the hill
Has been raised to the fame of the man in the mill.

So creative the powers of this strong silent man,
His labor brings forth from the clay,
The broad river's aerial spidery span,
The floating hotel on the bay,
And the forces of nature oft chained to the will,
Or led by the hand of the man in the mill.

The motor, the engine, he builds to a rule,
The crane to a specified plan,
Or a tireless, mechanical camel or mule,
For Egypt, or broad Hindustan;
And a pittance suffices the rough palm to fill
Of the right hand of Progress—this man in the mill.

Now charging the furnace with ore and with spar,
Now weaving the web's colors bright,
Now grinding the lens to examine that star
Hung on the great wall of the night;
So varied the craft, universal the skill
Of this Trojan who works day and night in the mill.

Oft, danger's red dragons are crouched at his back,
He feels their hot breath in the air,
No armour he wears to repel their attack,
His muscular arms are bare,
Unheeding he plies his chisel or drill
To lighten Life's burden—the man in the mill.

No plaudits are shouted to him on the stage,
No arches for victories won,
Tho his are the plan, equipment and gauge
Of rails that could girdle the sun.
His the compass, the caliper, never the quill,
Earth's servant and master—the man in the mill.

Let proud Wealth extend him on cusions of silk,
And Lucre her jewels display;
He shuns the diversions of those of that ilk,
His Master he came to obey—
To employ his one talent, his task to fulfill,
Hail! Drudgery's saviour—the man in the mill!

*Spike Factory, Joliet Works, Illinois Steel Company. Reprinted from the Mixer.

ARC WELDING—FEATURING RODS

At a meeting of the American Welding Society held at Pittsburgh, Pa., Tuesday, October 30, 1928, Mr. P. R. Hawthorne, Welding Engineer, of the Petroleum Iron Works at Sharon, Pa., presented a most interesting paper covering Arc Welding. The paper was illustrated with pictures of the products manufactured by the Petroleum Iron Works using arc welding as the producing tool.

One of the statements made by the author, which proves that Arc Welding must be reckoned with in the future tooling in Industry, was that they were able to deposit metal at the rate of 100 pounds per hour using a one-inch rod. He also brought out the fact that in order to produce a weld deposit which is free from oxygen and nitrogen, these elements which are present in the atmosphere, must be prevented from coming in contact with either the arc, the metal deposited, and from the deposited metal while it is in liquid form and until the temperature is below 1800 deg. Fahr. To protect the arc from open air by mechanical means would liberate, by the heat of the arc, a gas which will form a sheath or envelope around the arc, which by reason of its volume and density, will actually exclude or combine the harmful gases. This is, of course, most easily accomplished by using a chemical covering of the rod which will be consumed in direct proportion to the rate of the melting of the rod.

To protect the molten metal during the cooling and solidifying period there must be provided a chemical which will completely cover the same. This is also easily provided by adding to the rod covering a chemical which will distribute over the deposited metal and exclude air. This protective coating has the further advantage in that it prevents too rapid cooling and consequent chilling of the deposited metal. Further, to produce a perfectly welded sound weld, and one which is greater in tensile strength than the rolled rod, which is melted to form the deposit, it is necessary to introduce certain elements which will absorb completely the impurities in rod and parent metal and cause them to rise to surface from where they can be removed.

SUPER BLOWER

In line with much discussion regarding the use of compressed air for cleaning of equipment in engine rooms, motor rooms and sub stations, thus blowing dust from one machine to another, onto the switchboards and control and into instruments and relays, the Ideal Commutator Dresser Company has adapted the Super Giant Blower to the vacuum cleaning of such equipment through the use of various specially designed bristle nozzles, for getting down into windings, around uneven surfaces, all with safety, the nozzles being made of composition. Attachments are also available for general floor cleaning, wall cleaning and paint spraying.

The vacuum created by the Ideal Blower is considerably greater than that of household or stationery equipment, because of its tremendous speed and scientific design, yet, is very light in weight and easily carried by the strap furnished, slung over the shoulder.

The Roller-Smith Company, 233 Broadway, New York, N. Y., announces the appointment of Arthur H. Abbott, Inc., 88 Broad street, Boston, Mass., as its district sales agent for the New England territory, starting November 1, 1928.

STATEMENT OF OWNERSHIP, MANAGEMENT, ETC., OF

IRON AND STEEL ENGINEER

(Required by Act of Congress of August 24, 1912)

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Known bondholders, mortgagees and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages or other securities: None.

JOHN F. KELLY.

Sworn to and subscribed before me this 24th day of September, 1928.

JOHN G. HOSICK, Notary Public.

(My commission expires March 29, 1929.)

Decathlon champions and Condit Type F-120 Oil Circuit breakers—both must possess not only strength but speed, stamina, and agility, and all of these in superior measure. Condit's new Type F-120 leads the field as the result of many years' experience in design and building of heavy duty oil circuit breakers.

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